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All correspondence regarding articles from the Department of Agriculture should be addressed to Karl F. Kellerman, Journal of Agricultural Research, Washington, D. C.

*Dr. Pearl has undertaken special work in connection with the war emergency; therefore, until further notice all correspondence regarding articles from State Experiment Stations should be addressed to H. P. Armsby, Institute of Animal Nutrition, State College, Pa.

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ERRATA

Legend to Pl. 6: fig. 1 should be 2, fig. 2 should be 1.
Page 160, last line, "20 to 42" should read "55 to 115."
Page 161, Footnote, "Colletotrichum Higginscanum" should read "Colletotrichum Higginsianum."
Page 294, line 19 from bottom, "rachis" should read "rachilla."
Page 306, line 7 from bottom, "Pl. 46, B" should read "Pl. 46, C."
Page 314 should be 316, page 316 should be 314.
Page 439, line 5 from bottom, "Table IV" should read "Table VI."
Page 442, Table IX, "*Agropyron caninum*" should read "*Agrostis canina.*"
Page 442, Diagram 3, last line, $\frac{\text{"}\infty\text{"}}{25}$ should read $\frac{\text{"}2\text{"}}{25}$.
Page 448, line 2 below Table XVII, "Table XVI" should read "Table XVII."
Page 448, line 3 from bottom, "both" should read "all."
Page 468, Table XXIX, "*Agropyron stolonifera*" should read "*Agrostis stolonifera.*"
Page 485, line 13, "longer" should read "shorter."
Page 501, line 5 from bottom, "cochylis" should read "Conchylis."
Page 637, under "Literature cited," "(2) Lusk, Graham. The Elements of the Science of Nutrition. 326 p., 11 fig. Philadelphia and London." should read "(2) Lusk, Graham. 1914. The Fundamental Basis of Nutrition, p. 20, Yale Univ. Press."

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LIFE HISTORY OF PLUTELLA MACULIPENNIS, THE DIAMOND-BACK MOTH

By H. O. MARSH,

Scientific Assistant, Truck Crop and Stored Product Insect Investigations, Bureau of Entomology, United States Department of Agriculture

INTRODUCTION

In the Arkansas Valley of Colorado cabbage is grown on a moderate scale, chiefly for local consumption. As is usual with this crop, it is the host of numerous insect enemies, among which is the larva of the diamond-back moth (*Plutella maculipennis* Curtis [1]).

The writer has had the diamond-back moth under observation since 1908, and particularly since 1914. Throughout this period, except from the latter part of December, 1914, until early in March, 1915, when work was carried on at Phoenix, Ariz., all life-history observations were made at Rocky Ford, Colo.

DESCRIPTION OF THE DIAMOND-BACK MOTH

THE MOTH

The adult (Pl. 1, *A*) is a slender moth, grayish or brownish in general color, with ocherous markings on head, thorax, and wings. The female is usually lighter in color than the male. The wing expanse is about five-eighths of an inch, and, when at rest, the wings are folded close to the body. Flight is rather feeble and cautious, the moth usually coming to rest among the leaves of cruciferous vegetables or about cruciferous weeds. The nectar of such plants is the natural food of the adults, although in captivity they feed readily on diluted honey.

THE EGG

The egg is minute, scalelike, greenish white or yellowish in color, and is deposited singly, or rarely in groups of two or three, on the lower side of the leaves of cruciferous plants. In cool weather eggs of the first and last broods may be deposited on the upper side of the leaves, but this is apparently abnormal.

[1] Order Lepidoptera, family Yponomeutidae.

THE LARVA

The newly hatched larva is a minute, light-colored creature with a dark head. The mature larva (Pl. 1, *B*) is about three-tenths of an inch in length, slender, fusiform in shape, and dull green in color. The head is light colored and marked with brownish spots or lines.

In habit the larva is irritable, and, when disturbed, wriggles about actively. When feeding on tender-leaved plants (Pl. 1, *D*), the larva cuts entirely through the leaf, but with plants like cabbage, having thick leaves, it removes irregular areas of the lower surface without cutting through the upper epidermis. During cool weather the larvæ burrow into the leaves immediately after hatching, and for the following two to four days live in irregular blotch mines, which they form between the upper and lower epidermis.

THE PUPA

The pupa (Pl. 1, *C*) is slender, yellowish or whitish in color, and often striped with brown. It is about one-fourth of an inch in length and is inclosed in a beautiful, delicate, lacelike cocoon of white or grayish silken threads, attached to the leaves of the food plant, often along the midrib. In cool weather larvæ occasionally pupate in cracks in the soil about the base of the host plant.

DISTRIBUTION OF THE MOTH

The diamond-back moth is a cosmopolitan species which in the United States apparently occurs wherever cabbage (*Brassica oleracea capitata*) is grown.

In September and October, 1908, the several stages were noted by the writer on cabbage and turnip (*Brassica rapa*) at Santa Ana, Orange, Tustin, Garden Grove, Whittier, and Watts, Cal. From January to June, 1909, the larvæ were noted on cruciferous vegetables at Brownsville, Tex., and other localities in the lower Rio Grande Valley. In July and August, 1909, larvæ were noted on cabbage at Houston, Dallas, and Amarillo, Tex., and at Rocky Ford and Greeley, Colo. In December, 1909, and January, 1910, larvæ were found on cabbage and turnip at Lake Charles and Lake Arthur, La., and at Beaumont, Corpus Christi, San Antonio, Sabinal, and Laredo, Tex. From July, 1910, until February, 1911, larvæ were frequently found on cabbage, turnip, and watercress (*Radicula sinuata*) at Honolulu and Wahiawa, Oahu, Hawaiian Islands. At Honolulu the species was kept under fairly close observation, and it was noted that the larvæ did not become sufficiently numerous at any time to cause appreciable damage. During February and March, 1913, larvæ were noted on cabbage at Thermal, Coachella, Calexico, and El Centro, Cal. In May and June, 1913, larvæ were found on cabbage at Marion, N. C., and at Chester, N. J. All stages of this insect were found on various cruciferous plants at Phoenix, Glendale, Tempe, and other points in the Salt River Valley of Arizona during January and

February, 1915. In August, 1916, larvæ were noted on cabbage and turnip at Maxwell and French, N. Mex.

FOOD PLANTS

The larva of the diamond-back moth appears to feed exclusively on cruciferous plants. The writer has observed it feeding on the following cultivated varieties: Cabbage, cauliflower (*Brassica oleracea botrytis*), turnip, radish (*Raphanus sativus*), rape (*Brassica napus*), kale (*Brassica oleracea acephala*), mustard (*Brassica nigra*), "Chinese mustard" (*Brassica juncea*), kohlrabi (*Brassica oleracea caulo-rapa*), watercress (*Radicula sinuata*), horse-radish (*Radicula armoracea*), sweet alyssum (*Koniga maritima*), and candytuft (*Iberis amara*). While cabbage is decidedly the favorite, rape, cauliflower, turnip, and mustard are readily eaten.

Among weeds the writer noted the larvæ on only two species: Wild watercress (*Roripa sinuata*) and hedge mustard (*Sisymbrium* sp.), both being plants with mustard-like characteristics. Although the larvæ feed on the foliage of these weeds, they prefer the blossom buds or the blossoms, and are much more likely to be found among these than on the leaves. The watercress occurs in abundance along fences and irrigation laterals in the Arkansas Valley. It blossoms from early spring until late summer and supplies readily available food for the moths and larvæ. The hedge mustard, tentatively identified by Prof. J. J. Thornber, of the Arizona Experiment Station, as *Sisymbrium irio*, is a common weed in the irrigated sections of southern Arizona and blossoms throughout the winter.

SEASONAL HISTORY

At Rocky Ford, Colo., seven generations of the diamond-back moth occur annually. The winter is passed in the adult or moth stage. Moths which develop during October and November find shelter throughout the winter among the leaves of cabbage plants and other crop remnants left standing in the field.

In the spring following a dry "open" winter the moths are noticeably less numerous than after a winter of heavy snows; hence, it would appear that snow serves as an additional protection for the hibernating adults. Although larvæ and pupæ occur in small numbers in the field during November and occasionally in early December, they do not survive the winter. The writer repeatedly experimented with larvæ and pupæ, both indoors and out, to determine their resistance to cold, and in every case all died during the late fall or early winter. The most painstaking examination during the spring months failed to reveal a single living larva or pupa on cabbage or other plants standing in the field or stored in cellars or pits.

On the other hand, the writer found living moths in the field at Rocky Ford throughout the entire winter. They usually hibernate among the dead or drooping leaves of cabbage plants, crawling between the leaves, with the advent of the first severe frosts, where they remain concealed

until the following spring. Usually the moths remain motionless, although on exceptionally warm winter days they may fly a little if disturbed.

The moths emerge from hibernation early in May and fly to the blossoms of cruciferous plants, usually the wild watercress (*Roripa sinuata*), to feed. In 1914, 1915, and 1916 the overwintered moths were first noted on the wing on May 4, 3, and 1, respectively. Copulation takes place shortly after the moths begin to fly, and oviposition commences within a day or two, the eggs of the overwintered females usually being deposited on the watercress. Occasionally the foliage of turnips which have been protected throughout the winter by snow or stored in pits is available for this purpose. Reproduction continues throughout the summer and until the severe freezes of late fall kill off the last belated larvæ and pupæ. In the Arkansas Valley the larvæ are most numerous in June or early July, the later generations being greatly reduced by parasites. The moths are most numerous during the fall, when they frequently occur in considerable numbers about cabbage and other cruciferous vegetables.

At Rocky Ford the egg stage covered from 3 to 6 days, the larva stage from 9 to 28 days, and the pupa stage from 5 to 13 days, the life cycle from egg to adult thus occupying from 17 to 47 days.

In the South the diamond-back moth is active throughout the year, and the larvæ are to be found at all seasons.

LIFE HISTORY OF THE MOTH

The principal life-history studies of the diamond-back moth were carried out at Rocky Ford, Colo., from 1914 to 1916. The insects were confined in battery-jar cages under open-air conditions. The moths were fed with the blossoms (nectar) of cruciferous plants or with diluted honey, and the larvæ were reared on cabbage or turnip foliage.

On May 4, 1914, several overwintered moths which had just issued from hibernation were captured in the field and confined in a cage. Their record is given in Table I.

TABLE I.—*Record of the generations of Plutella maculipennis at Rocky Ford, Colo., in 1914*

Item.	First generation.	Second generation.	Third generation.	Fourth generation.	Fifth generation.	Sixth generation.	Seventh generation.
Moths captured and confined	May 4	.....	.....	.....	.....	.....	.....
First adults issued	.....	June 1	June 19	July 7	July 25	Aug. 13	Sept. 7
First eggs deposited	May 6	June 2	June 20	July 8	July 26	Aug. 14	Sept. 8
First eggs hatched	May 11	June 6	June 23	July 11	July 29	Aug. 17	Sept. 12
First cocoons formed	May 23	June 13	July 1	July 20	Aug. 7	Aug. 31	Sept. 23
First larvæ pupated	May 24	June 14	July 2	July 21	Aug. 8	Sept. 2	Sept. 25
First adults issued	June 1	June 19	July 7	July 25	Aug. 13	Sept. 7	Oct. 3
Egg stage.....days..	5	4	3	3	3	3	4
Larval stage.....do....	13	8	9	10	10	16	13
Pupal stage.....do....	7	5	5	4	5	5	8
Total duration.....do....	25	17	17	17	18	24	25

The moths of the seventh generation, which issued on October 3 and 4, 30 in number, remained in the cage in which they were reared until November 9. They fed on diluted honey, but deposited no eggs. On November 9 they were transferred to a cage containing a dead cabbage plant and 2 inches of moistened soil and placed in the laboratory cellar. They crawled in among the dead leaves or clung to the underside of the cloth cover of the cage, becoming semidormant throughout the winter. From December, 1914, until March, 1915, during the writer's absence, the cage was neglected and the soil became dry, which was apparently detrimental to the moths, as several died.

On April 5, 1915, the cage was taken from the laboratory cellar and placed in a slightly heated room in the laboratory. Six moths were alive and apparently in good condition. They remained partially dormant until April 30, when they became active and began to feed. On May 2 the first eggs were deposited and others were deposited at intervals until May 14. Illness at this time occasioned the loss of these eggs.

REARING RECORDS FOR 1915–16

On August 18, 1915, life-history studies were resumed with fresh material collected in the field. Merely for the sake of convenience the first brood reared from this material will be arbitrarily designated the "first generation," although in reality it is the sixth generation which developed in 1915. The records of the seven generations of 1915–16 are given in Table II.

TABLE II.—*Record of the generations of Plutella maculipennis at Rocky Ford, Colo., in 1915–16*

Item.	First generation.	Second generation.	Third generation.	Fourth generation.	Fifth generation.	Sixth generation.	Seventh generation.
Adults issued and confined	1915 Aug. 18	1915	1915	1916	1916	1916	1916
First adults issued		Sept. 12	[a]Nov. 2	June 1	June 29	July 18	Aug. 5
Adults mated			1916. May 3				
First eggs deposited	Aug. 19	Sept. 16	May 4	June 10	July 1	July 20	Aug. 6
First eggs hatched	Aug. 23	Sept. 22	May 8	June 14	July 4	July 23	Aug. 10
First cocoons formed	Sept. 4	Oct. 18	May 25	June 24	July 12	July 31	Aug. 22
First larvæ pupated	Sept. 5	Oct. 20	May 26	June 25	July 13	Aug. 1	Aug. 24
First adults issued	Sept. 12	Nov. 2	June 1	June 29	July 18	Aug. 5	Aug. 30
Egg stage.....days..	4	6	4	4	3	3	4
Larval stage.....do....	13	28	18	11	9	9	14
Pupal stage.....do....	7	13	6	4	5	4	6
Total duration.....do....	24	47	28	19	17	16	24

[a] Or Nov. 3.

Fifty-two adults, about equally divided as to sex, developed on November 2 and 3. These moths were confined in battery jars containing moistened earth and dead cabbage plants, and on November 10 were placed in the laboratory cellar. Throughout the winter the cages were examined and the soil moistened at frequent intervals. On May 2,

1916, the cages were taken from the cellar and placed in the open-air rearing shelter. Thirty moths were alive at this date. It was noted that many more males than females died during the winter. The moths fed eagerly on diluted honey. On May 3 one pair mated and was isolated in another cage. The record for this pair is given in Table II (third generation).

The experiment with this material, having been carried a full year, was discontinued on August 30, 1916. For some unknown reason the moths which issued on June 1 deposited no eggs until June 10, and this largely accounts for the overlapping (August 19 to 30, 1916) of the life cycle.

During 1916 the preceding life-history studies were verified by a duplicate set of rearing experiments. The records are essentially the same as those given in Table II, and the details will therefore be omitted.

On May 3, 1916, a male and two females which had just issued from winter quarters were captured about the blossoms of watercress and confined in a cage. On May 4 the male mated with one of the females, and the first eggs, 50 in number, were deposited on this day. On May 5, 61 eggs were deposited. The first eggs hatched on May 7, and from this material the species was reared throughout the season. The dates on which the adults of the seven successive generations issued are given in Table III.

TABLE III.—*Date of issue of adults of seven generations of Plutella maculipennis at Rocky Ford, Colo., 1916*

May 31	Adults of first generation issued.
June 27	Adults of second generation issued.
July 16	Adults of third generation issued.
Aug. 4	Adults of fourth generation issued.
Aug. 25	Adults of fifth generation issued.
Sept. 22	Adults of sixth generation issued.
Nov. 6	Adults of seventh generation issued.

The adults of the seventh generation were confined in the usual way and placed in the laboratory cellar on November 10, 1916. At the time this article was written, late in December, 1916, these moths were hibernating in excellent condition.

REARING RECORDS AT PHOENIX, ARIZ.

In addition to the life-history studies carried on at Rocky Ford, Colo., the writer reared the diamond-back moth through one generation at Phoenix, Ariz. There the cages were kept in an open, unheated hallway where the temperature varied little from that prevailing out of doors.

On December 30, 1914, a few nearly mature larvæ were collected from turnips in a garden at Phoenix and confined. The first cocoons were formed on January 2, 1915, and the first larvæ pupated on January 3. The first adults, three in number, issued on January 20 and 21. These moths were isolated in another cage. The record is given in Table IV.

TABLE IV.—*Rearing records of Plutella maculipennis at Phoenix, Ariz., in 1914*

Jan. 20–21	First adults issued.
Jan. 23	First eggs deposited.
Feb. 5	First eggs hatched.
Feb. 17	First cocoons formed.
Feb. 19	First larvæ pupated.
Mar. 2	First adults issued.

As noted in Table IV the stages are as follows:

	Days.
Egg stage	13
Larva stage	14
Pupa stage	11
Total duration	38

The larvæ reared at Rocky Ford during May lived as leaf-miners for the first two or three days of their existence, whereas those reared at Phoenix during February lived in mines for four days. At Rocky Ford during October and at Phoenix during January and February many of the older larvæ changed to a dark, dull-green color and were marked with reddish spots. The mining habit and the changes in coloration occurred with larvæ in the field as well as those confined in cages and were obviously induced by low temperature.

EGG-LAYING RECORDS

Egg-laying records were obtained at Rocky Ford by confining single pairs of moths, immediately after they issued, in large jelly glasses. The moths were fed diluted honey or the nectar of watercress. A cabbage leaf was placed in each cage daily, and upon these leaves the eggs were deposited. The eggs were counted daily and destroyed. The number of eggs deposited by nine females which issued during July and August were 287, 116, 413, 202, 237, 427, 282, 168, and 451, respectively, or an average of 287 eggs per female.

A detailed record of the female of one of these pairs of moths, which issued on August 16, is given in Table V.

TABLE V.—*Egg-laying record of a single female of Plutella maculipennis at Rocky Ford, Colo., in 1916*

	Eggs deposited.
Aug. 17	26
Aug. 18	78
Aug. 19	69
Aug. 20	43
Aug. 21	32
Aug. 22	23
Aug. 23	11
Total	282

Both moths died on August 23, having lived 7 days. In the cooler weather of spring and fall the life of the moths and the egg-laying period are lengthened and may cover from 10 to 14 days.

NATURAL ENEMIES [1]

The diamond-back moth is a striking example of a potentially serious pest normally held in repression by parasites. The most effective species engaged in this beneficial work is an ichneumonid, *Angitia plutellae* Vier. (Pl. 2, *A*). The writer reared this parasite from larvæ of the diamond-back moth collected at various points in the Arkansas Valley, at Colorado Springs, Colo., and at Phoenix, Ariz. In Colorado it is active whenever Plutella larvæ are in evidence. In Arizona it appears to work throughout the year. With the later generations of the diamond-back moth it is not unusual to find from 50 to 70 per cent of the larvæ infested by this parasite.

Parasitized larvæ of *P. maculipennis* reach maturity and form their cocoons. The larvæ of *Angitia plutellae*, one from each infested Plutella larva, issue and spin compact gray cocoons within the Plutella cocoons. Unfortunately the larvæ of *A. plutellae* are occasionally infested by a chalcidid hyperparasite, *Spilochalcis delira* Cresson (Pl. 2, *B*). The writer had *A. plutellae* under observation at Rocky Ford during the years 1911 to 1916, and at no time during this period was the hyperparasite sufficiently numerous to reduce noticeably the numbers of its host.

Other parasites reared by the writer at Rocky Ford from the larvæ of the diamond-back moth were identified as *Meteorus* sp. and *Mesochorus* sp., and a new species of Microplitis. These parasites were, however, too rare to be of noticeable benefit in reducing the numbers of the larvæ of *P. maculipennis*.

No parasites were reared by the writer from the eggs or pupæ of the diamond-back moth, and no predacious or fungus enemies have been observed.

EXTENT OF INJURY

Although the larvæ of the diamond-back moth feed on many cruciferous plants, they seldom cause appreciable damage to any except cabbage, cauliflower, and rape. In Colorado the larvæ are usually sufficiently numerous on these plants during June or early July to riddle the leaves badly. The later generations are so effectively held in check by parasites that little or no damage results. Whenever damage occurs, it is always most serious with young plants. Sometimes the larvæ crawl in among the leaves of newly transplanted cabbage and feed on the tender leaves at the center. In such cases the heads, if any develop, are usually deformed and worthless.

[1] The ichneumonids were identified by Mr. A. B. Gahan, of the Bureau of Entomology, and the chalcidid by Mr. J. C. Crawford, of the United States National Museum.

CONTROL MEASURES

During the years 1909–1916 the writer made many insecticide experiments to determine the best means of controlling the various "worms," including the larvæ of the diamond-back moth, which infest cabbage and related vegetables. Tests were made with Paris green, arsenate of lead, zinc arsenite, nicotine sulphate, and soap solutions. In the writer's experience the following mixture, applied as a spray, is unquestionably the most effective remedy against the larvæ of the diamond-back moth on cabbage.

Paris green	pounds	2
Soap	do	6
Water	gallons	100

In small plantings this mixture may be applied with a portable compressed-air knapsack sprayer, fitted with an extension rod, elbow, and a nozzle of the disk or Vermorel type having a fine aperture. The application should be thorough, and, as an adhesive is required, owing to the waxy "bloom" of the leaves, common laundry soap will be found satisfactory and is always cheap and available.

Powdered arsenate of lead, applied at the rate of 4 pounds in 100 gallons of water, is another effective remedy for worms on cabbage and at present, owing to the abnormal conditions brought about by the war in Europe, is cheaper than Paris green.

Unfortunately considerable prejudice exists against the use of arsenicals on cabbage. This feeling is groundless and should be discouraged.

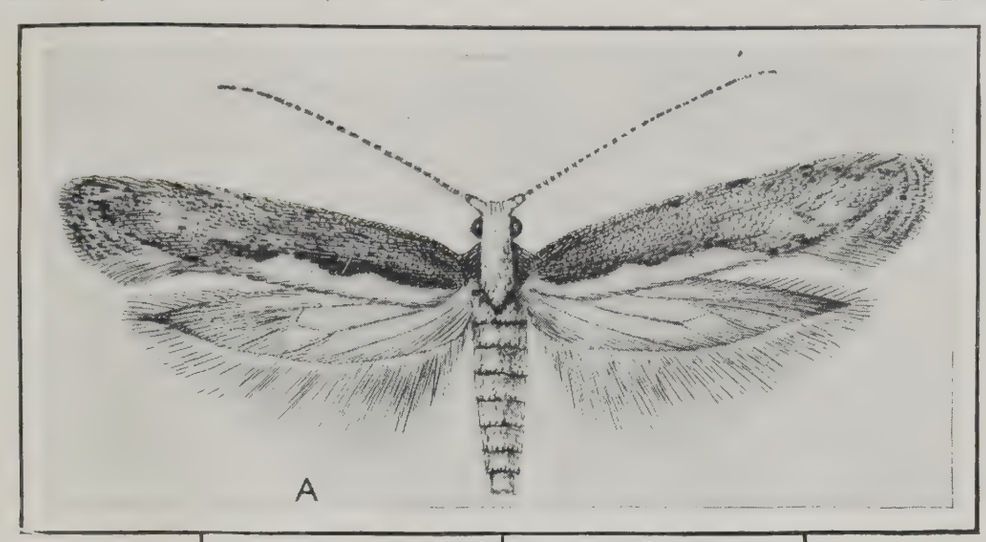
CONCLUSION

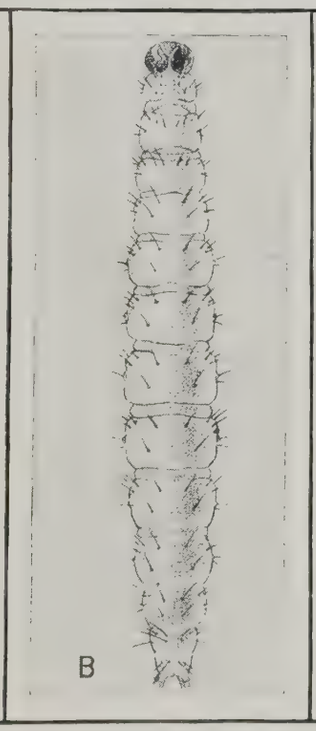
The diamond-back moth (*Plutella maculipennis*) is a cosmopolitan species widely distributed in the United States. The larvæ are slender, green "worms" which infest many varieties of cruciferous plants but seldom cause appreciable injury to any except cabbage, cauliflower, and rape. At Rocky Ford, Colo., seven generations, or broods, develop annually. The life cycle from egg to adult is passed in from 16 to 47 days. In the Southern States this insect is active throughout the year.

Although it develops with remarkable rapidity and is capable of causing extensive damage if unchecked, the diamond-back moth is so effectively held in repression by parasites that it rarely becomes more than a minor pest. Whenever the parasites are inactive and the larvæ become sufficiently numerous to demand attention, they may be readily controlled by spraying the infested plants with an arsenical.

PLATE 1

A.—*Plutella maculipennis:* Adult. Much enlarged. Original.
B.—*Plutella maculipennis:* Larva. Enlarged. Original.
C.—*Plutella maculipennis:* Pupa. Enlarged. Original.
D.—Leaf of mustard, showing injury by *Plutella maculipennis*. From Jones.


A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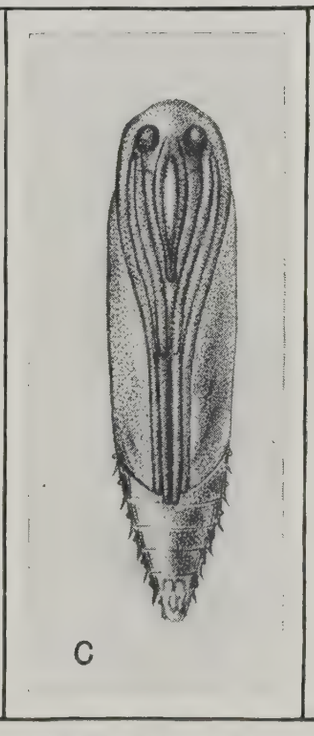
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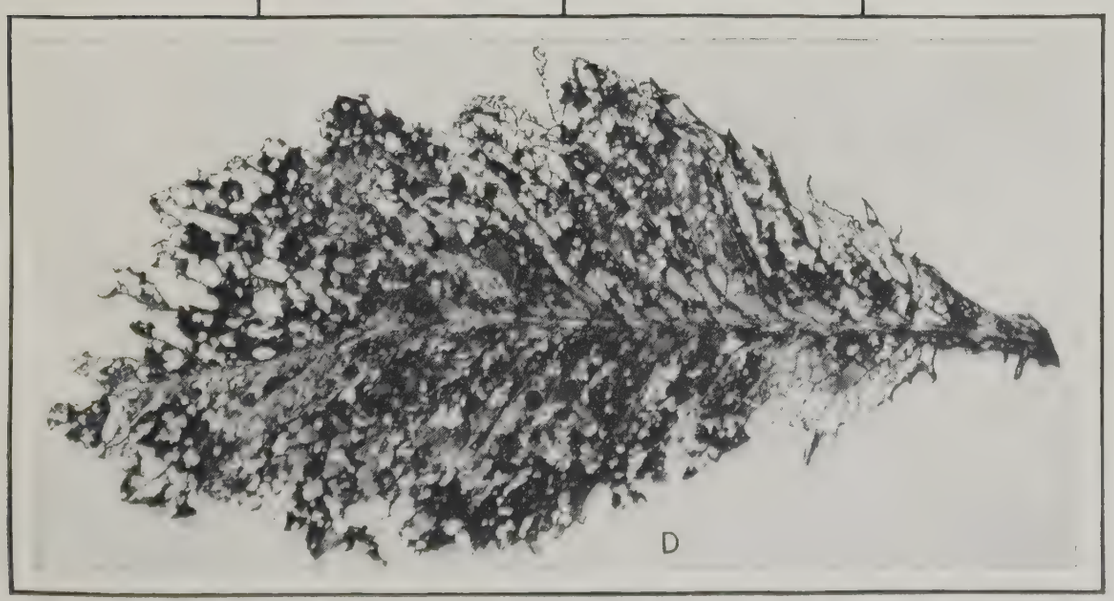

D

A

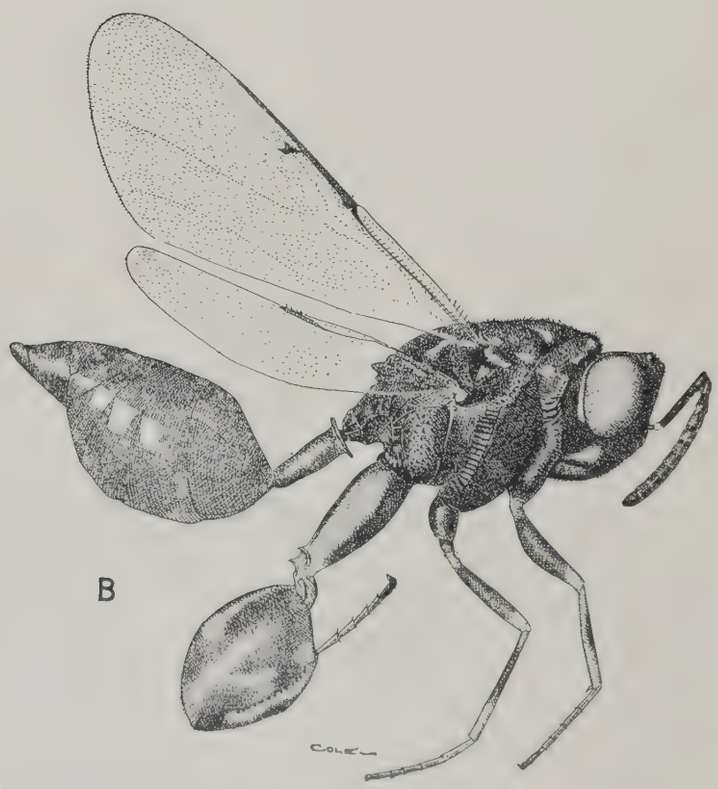

B

PLATE 2

A.—*Angitia plutellae*, parasite of *Plutella maculipennis*. Original.

B.—*Spilochalcis delira*, a parasite on *Angitia plutellae*, and therefore a secondary or injurious parasite. Highly magnified. Original.

DAILY VARIATION OF WATER AND DRY MATTER IN THE LEAVES OF CORN AND THE SORGHUMS

By EDWIN C. MILLER,[1]

Assistant Plant Physiologist, Department of Botany,
Kansas Agricultural Experiment Station

INTRODUCTION

In connection with the study of the water relations of corn and the nonsaccharin sorghums previously reported by the writer,[2] it was thought advisable to determine the daily variation of the water and dry matter in the leaves of these plants. A knowledge of the variation of the water in the leaves should throw some light on the relative ability of these plants to absorb water from the soil and to transport it to regions of loss from transpiration, while a study of the daily variation of dry matter in the leaves would permit a comparison of the relative power of the plants to manufacture food under different climatic conditions. The experiments herein reported were conducted during the summers of 1914, 1915, and 1916 at the State branch Experiment Station at Garden City, Kans.

EXPERIMENTAL METHODS

CULTURAL METHODS

The plants used in these experiments were Pride of Saline corn (*Zea mays*), Blackhull kafir (*Andropogon sorghum*), and Dwarf milo (*A. sorghum*). In 1914 and 1915 the plants were grown in alternate rows on the same plot, while in 1916 the experiments were made with plants grown on a series of one-twentieth-acre plots. The plants were grown in a sandy-loam soil that had been fall-plowed and irrigated with approximately 8 inches of water. The crops were surface-planted in rows 44 inches apart. After the plants were a few inches high the corn was thinned to a distance of 2 feet between the plants, Blackhull kafir to 1½ feet, and the Dwarf milo to 1 foot. The plots were scraped with a hoe to keep the weeds down, but no other cultivation was given during the growing season. They received no water after the fall irrigation, except that which came from the rainfall.

[1] Acknowledgments are due Mr. J. L. Jacobson for his aid in collecting material in 1914 and to Mr. W. B. Coffman for his general assistance in all phases of this work.

[2] MILLER, E. C. COMPARATIVE STUDY OF THE ROOT SYSTEMS AND LEAF AREAS OF CORN AND THE SORGHUMS. *In* Jour. Agr. Research, v. 6, no. 9, p. 311–332, 3 fig., pl. 38–44. 1916. Literature cited, p. 331.

———. RELATIVE WATER REQUIREMENT OF CORN AND THE SORGHUMS. *In* Jour. Agr. Research, v. 6, no. 13, p. 473–484, 1 fig., pl. 70–72. 1916.

In order to define better the conditions under which the plants were grown, soil samples for moisture determination were taken for each foot to a depth of 6 feet. This was done either a few days before or after the experimental work with the leaves. The results of these moisture determinations, together with the wilting coefficient and moisture equivalent for the several plots, are shown in Table I.

TABLE I.—*Moisture content of the soil at the time the leaf samples were taken in 1914, 1915, and 1916, at Garden City, Kans.*

Item.	Percentage of moisture, wilting coefficient, and moisture equivalent to a depth of—					
	1 foot.	2 feet.	3 feet.	4 feet.	5 feet.	6 feet.
Corn-milo-kafir plot:						
July 2, 1914	14.6	20.2	21.2	22.8	22.1	21.8
July 10, 1914	11.8	17.1	19.5	23.6	24.6	21.4
July 21, 1914	10.6	13.3	14.5	19.4	22.8	21.7
July 29, 1914	8.7	13.1	13.5	16.8	21.4	21.0
Wilting coefficient	*12.7*	*14.5*	*14.5*	*16.3*	*17.1*	*16.1*
Moisture equivalent	*23.4*	*26.7*	*26.7*	*30.0*	*31.5*	*29.6*
July 29, 1914	10.3	15.7	16.2	18.4	19.8	20.1
August 12, 1914	10.2	14.9	14.1	15.2	17.7	19.6
August 22, 1914	9.5	14.9	14.1	14.4	15.5	18.8
July 12, 1915	16.2	20.8	20.2	17.8	19.0	15.5
August 6, 1915	14.2	15.2	15.4	16.0	16.1	15.4
Wilting coefficient	*13.3*	*14.1*	*14.9*	*13.6*	*13.4*	*11.9*
Moisture equivalent	*24.4*	*25.9*	*27.5*	*25.1*	*24.6*	*21.9*
Corn plot:						
July 20, 1916	10.0	14.7	19.0	21.9	23.6	24.2
August 1, 1916	7.3	11.8	14.0	18.1	21.4	22.0
August 10, 1916	7.5	11.5	12.5	14.6	18.7	20.8
Wilting coefficient	*12.3*	*15.9*	*12.4*	*15.0*	*16.3*	*16.4*
Moisture equivalent	*22.6*	*29.3*	*23.0*	*27.7*	*30.1*	*30.2*
Milo plot:						
July 20, 1916	11.1	15.4	19.6	22.2	24.1	24.8
August 1, 1916	8.3	9.9	14.6	14.9	20.8	24.0
August 10, 1916	8.0	11.8	14.1	13.6	18.6	21.4
Wilting coefficient	*12.2*	*13.4*	*15.1*	*14.3*	*15.4*	*15.6*
Moisture equivalent	*22.4*	*24.6*	*27.8*	*26.3*	*28.3*	*28.6*
Kafir plot:						
August 10, 1916	7.0	11.0	11.7	13.6	21.1	22.6
Wilting coefficient	*12.7*	*12.3*	*15.3*	*13.9*	*16.9*	*17.8*
Moisture equivalent	*23.3*	*22.5*	*28.2*	*25.6*	*31.3*	*32.8*
July 26, 1916	10.8	16.9	19.3	21.9	22.1	21.2
Wilting coefficient	*12.7*	*14.5*	*14.5*	*16.3*	*17.1*	*16.1*
Moisture equivalent	*23.4*	*26.7*	*26.7*	*30.0*	*31.5*	*29.6*

EVAPORATION

Hourly evaporation was determined by Livingston's porous-cup atmometers with a coefficient of 74. The atmometers were placed 2 feet from the ground and connected with burettes so that readings could be made to 0.1 c. c. These atmometers were renewed every three weeks during the periods of the experiments. The evaporation obtained in this manner for each 2-hour period is shown in Table II.

TABLE II.—*Evaporation (in cubic centimeters) for the different periods of leaf sampling in 1914, 1915, and 1916, at Garden City, Kans.*

Date.	Evaporation for period ending—																			
	A. M.			P. M.						A. M.						P. M.				
	7	9	11	1	3	5	7	9	11	1	3	5	7	9	11	1	3	5	7	9
1914.																				
June 24	....	9.8	14.1	17.4	21.7	18.3	14.5	....	....	....	....	....	....	....	....	....	....	....	....	....
July 9	....	5.8	7.8	11.7	12.1	10.8	11.3	3.8	....	....	....	....	....	....	....	....	....	....	....	....
July 13	....	3.7	5.3	8.6	9.7	9.0	9.7	4.3	2.0	....	....	....	....	....	....	....	....	....	....	....
July 22	....	2.8	6.1	8.1	9.5	7.0	4.1	2.9	....	3.5	2.3	1.5	....	....	....	....	....	....	....	....
July 28–29	....	6.4	9.9	14.6	15.8	15.2	13.7	5.6	4.6	....	....	....	....	....	....	....	....	....	....	....
Aug. 3–4	....	5.3	9.7	10.5	11.2	11.3	8.7	4.0	2.9	3.6	2.4	2.3	2.8	6.5	13.7	15.6	....	....	....	....
Aug. 10–11	4.0	7.8	12.1	13.2	14.6	12.7	8.7	5.3	4.3	1.9	0.7	0.6	2.0	5.8	8.8	12.5	4.3	2.2	....	....
Aug. 15–16	2.0	9.4	13.1	18.3	23.8	21.6	14.0	8.4	6.8	4.9	2.7	1.2	3.2	9.8	16.7	23.6	24.7	20.8	16.5	8.1
Aug. 25–26	....	6.3	11.5	13.8	13.3	12.2	9.8	5.6	3.8	2.7	0.6	1.8	3.1	6.3	9.7	12.1	14.9	13.9	8.8	4.9
1915.																				
July 17–18	4.4	8.0	11.6	15.2	16.5	15.7	11.2	4.3	3.9	4.1	3.4	1.8	3.1	....	....	....	....	....	....	....
July 31–Aug. 1	0.8	5.1	9.0	12.7	13.0	10.6	6.6	3.0	1.5	1.1	0.5	0.9	1.7	4.5	8.3	11.7	12.5	13.1	9.1	....
1916.																				
July 20–21	2.0	4.9	7.5	11.8	14.3	14.6	13.5	8.1	7.1	2.5	1.5	1.0	3.6	9.3	12.8	15.3	17.8	....	....	....
July 26–27	7.2	10.2	15.3	18.2	18.7	19.0	16.5	10.2	7.6	4.2	2.3	1.5	3.4	8.3	10.7	15.3	16.9	16.4	12.9	....
Aug. 1–2	3.4	8.5	14.5	17.0	18.1	15.5	12.8	8.7	7.4	5.5	4.5	3.6	5.2	11.6	18.3	20.3	20.6	19.5	....	....
Aug. 10–11	3.2	7.6	13.6	13.3	14.1	15.8	12.9	10.6	4.7	5.6	5.4	3.1	3.7	6.6	8.9	12.9	15.3	14.7	9.2	....

LEAF SAMPLING

The amount of water and dry matter in the leaves of a given variety of plant was determined every two hours from 30 leaf samples, each with an area of 1 square centimeter. Thirty representative plants of each variety were selected and a leaf chosen on each plant for furnishing all the samples for an experiment extending over the desired length of time. Plate 3 shows the manner in which the leaf samples were obtained. This figure shows the appearance of milo, corn, and kafir leaves at the end of a 40-hour experiment. At 7 a. m. a single sample was taken from each of the 30 selected leaves at *a* and toward the tip of the leaf. This was done by means of a Ganong leaf punch taking an area of 1 square centimeter. At 9 a. m. a sample was taken from each of the 30 leaves at *b*, directly opposite *a*. At 11 a. m. the samples were collected from the leaves at *c*, directly below *a*, then at the next 2-hour period at *d*, and so on. The samples for a 40-hour experiment were thus obtained from a portion of the leaves representing less than 6 inches of their respective lengths. The leaf samples from corn, kafir, and milo at any period could be collected in the manner described in from five to eight minutes. Care was taken in the selection of the leaves, so that they would be as nearly the same age as possible for the three plants. The uppermost fully developed leaf of each plant was the one from which the leaf samples were obtained.

The samples were collected in weighed vials which were then quickly stoppered. The vials containing the moist material were weighed at once on balances sensitive to 0.1 mgm. They were then placed in a

drying oven at 100° to 105° C. until all the moisture was driven off. After drying, the samples were cooled in a desiccator over sulphuric acid and weighed, so that the amount of water and dry matter could be obtained.

STAGES EXAMINED

The experiments for the three years were conducted with plants at approximately five stages of development.

STAGE I.—The corn plants had a height of 1 foot 6 inches and possessed 4 fully and 4 partially unfolded leaves. The milo and kafir had the same number of leaves as the corn, but the plants had reached a height of only 1 foot. The experiments of June 24 and July 9, 1914, were conducted with plants at this stage of development.

STAGE II.—The experiments reported for July 13 and 22, 1914, and for July 20–21 and 26–27, 1916, were made with plants at this stage. The corn plants were from 3 feet to 3 feet 6 inches high and had 8 to 10 fully unfolded and 3 to 5 partially unfolded leaves. The Dwarf milo stood 2 feet high and was just beginning to "boot," while the Blackhull kafir had 6 fully and 4 partially unfolded leaves and had reached a height of from 2 feet to 2 feet 6 inches.

STAGE III.—The corn had reached a height of from 4 to 5 feet. The plants had from 12 to 14 leaves and the tassels were just showing. The kafir stood 3 feet 6 inches high and showed 8 fully and 3 partially unfolded leaves. The milo plants were just past the "booting" stage and had from 10 to 12 leaves on a plant. The experiments of July 17 and 18, 1915, and of August 1 and 2, 1916, were conducted with plants at this period of growth.

STAGE IV.—Plants at this stage of development furnished the material for experiments carried on July 28–29, August 3–4, 10–11, 15–16, 1914; July 31, August 1, 1915, and for the experiment of August 10–11, 1916. The corn plants had reached their full leaf development, and the ears were beginning to form. The kafir stood 4 to 5 feet high, and in most cases the plants were just beginning to "boot." The milo was 3 feet 6 inches high and for the various experiments was in stages of development from blooming to the milk stage of the grain.

STAGE V.—The experiment of August 25–26, 1916, was the only one conducted at this period of development. The grain of the corn had reached the early milk stage, the kafir was in bloom, and the grain of the milo was ready to harvest.

GENERAL DISCUSSION OF EXPERIMENTAL DATA

Nine experiments were conducted in 1914, two in 1915, and four in 1916. Four of the experiments in 1914 extended only through the daylight hours, but all of the other experiments ranged in length from 24 to 40 hours. In all, the amount of water and dry matter in the leaves was

determined every two hours for 22 days and 10 nights. The amount of water in the leaves at any period of the night could be accurately determined, owing to the fact that dew is very rare during the summer in this portion of the Great Plains. Corn, kafir, and milo were used in all the experiments, with but two exceptions in 1916. In these two experiments only corn and milo were used. The results for the three years are shown in Tables III and IV. The amount of water in the leaves is expressed in grams per square meter of leaf; percentage on a wet basis and dry basis for each 2-hour period of the experiment. The amount of dry matter is expressed in grams per square meter of leaf and in percentage of the moist weight of the leaf. The data shown in Tables III (July 28, 1914–Aug. 11, 1916) and IV are expressed graphically in figures 1 to 10. In discussing these data the day periods include the determinations made from 7 a. m. to 7 p. m., inclusive, and the night periods include the observations made from 7 p. m. to 7 a. m., inclusive.

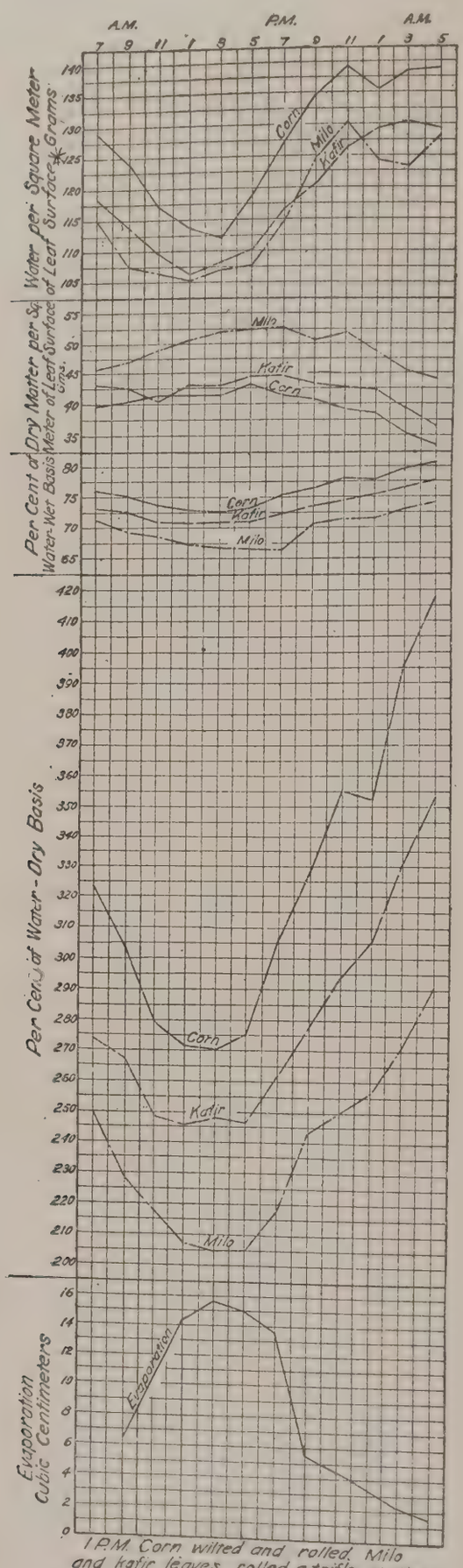


FIG. 1.—Graphs showing the amount of water and dry matter in the leaves of corn, kafir, and milo for July 28 and 29, 1914, and the evaporation for the corresponding period.

* Leaf surface is used in these figures as the equivalent of leaf area.

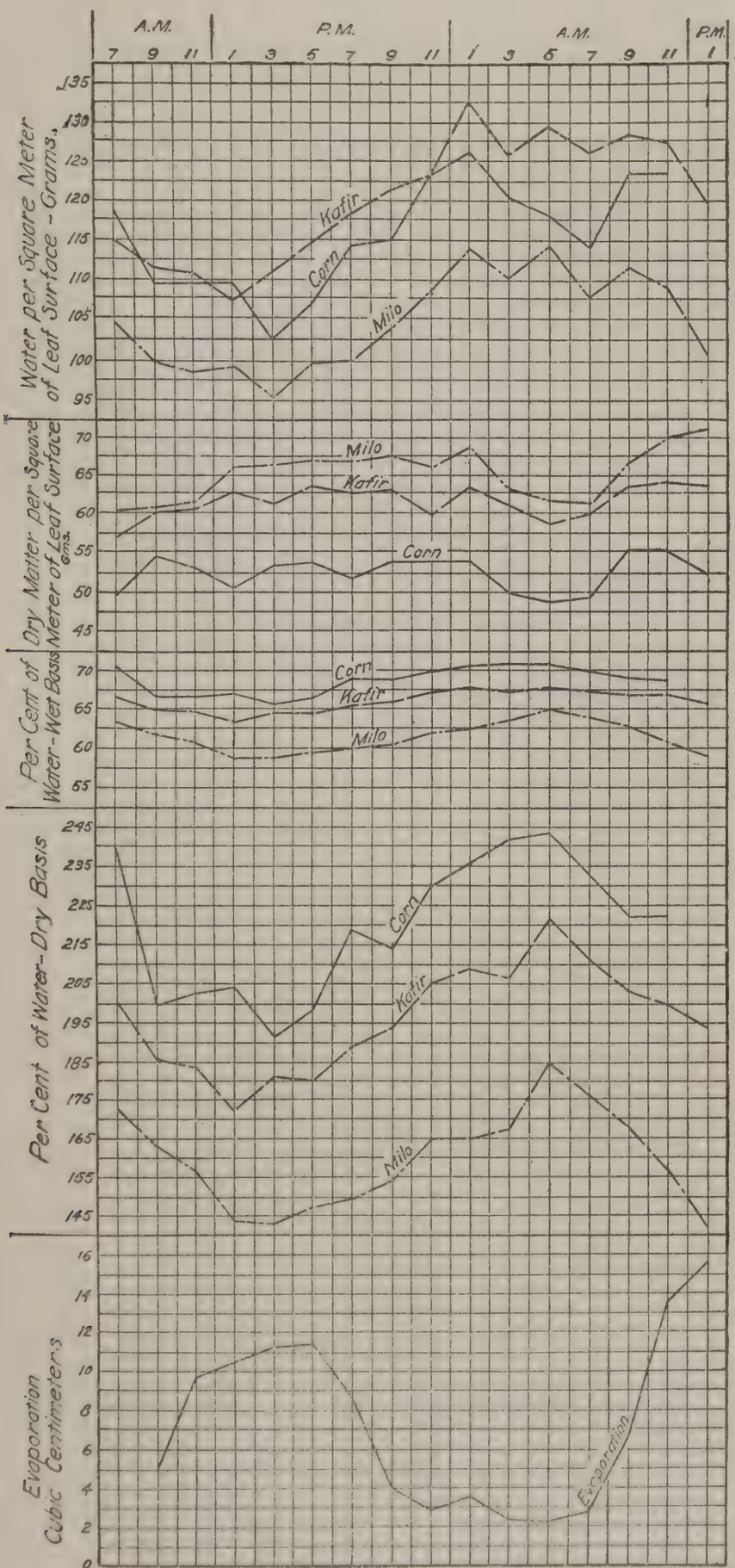


FIG. 2.—Graphs showing the amount of water and dry matter in the leaves of corn, kafir, and milo for August 3 and 4, 1914, and the evaporation for the corresponding period.

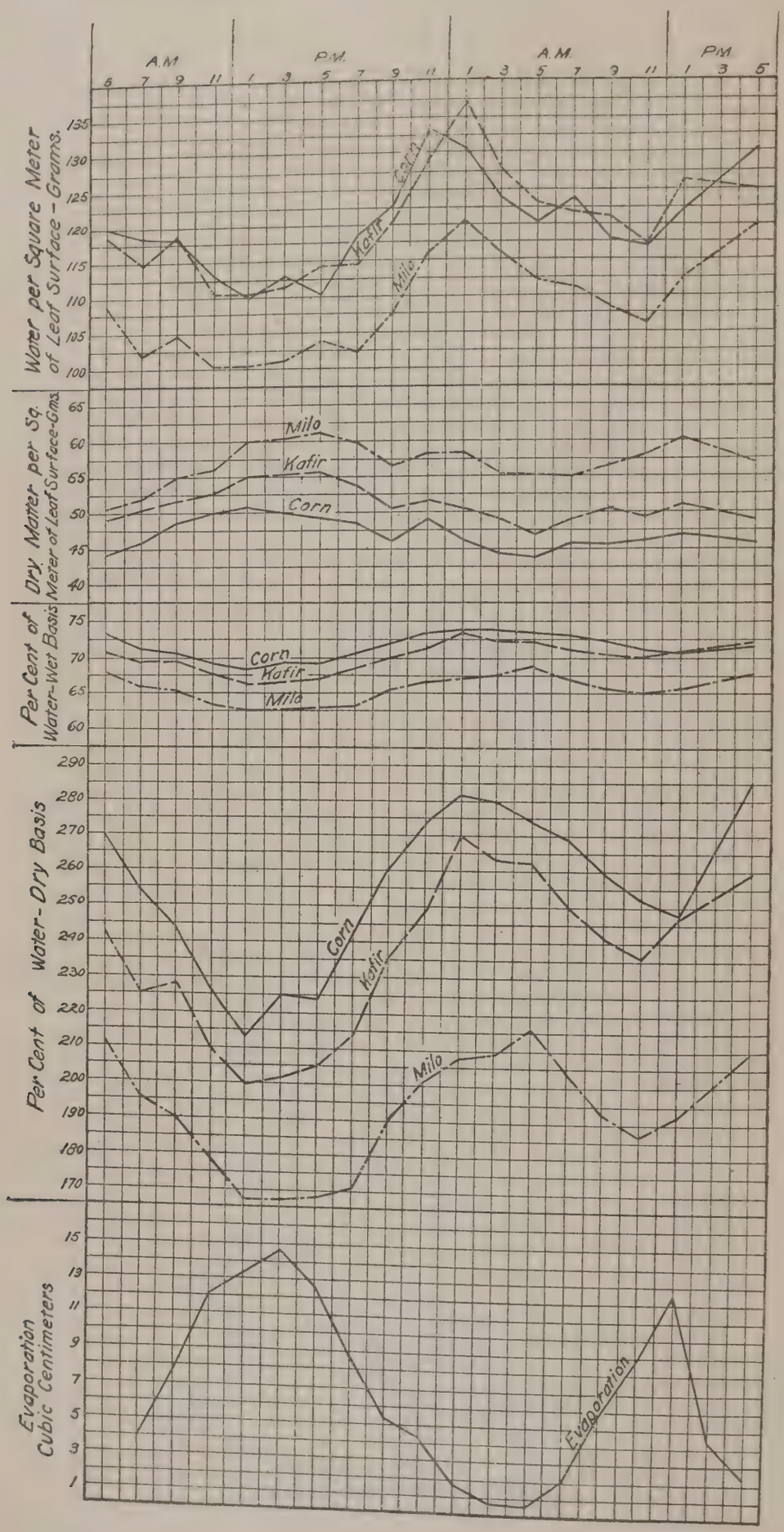
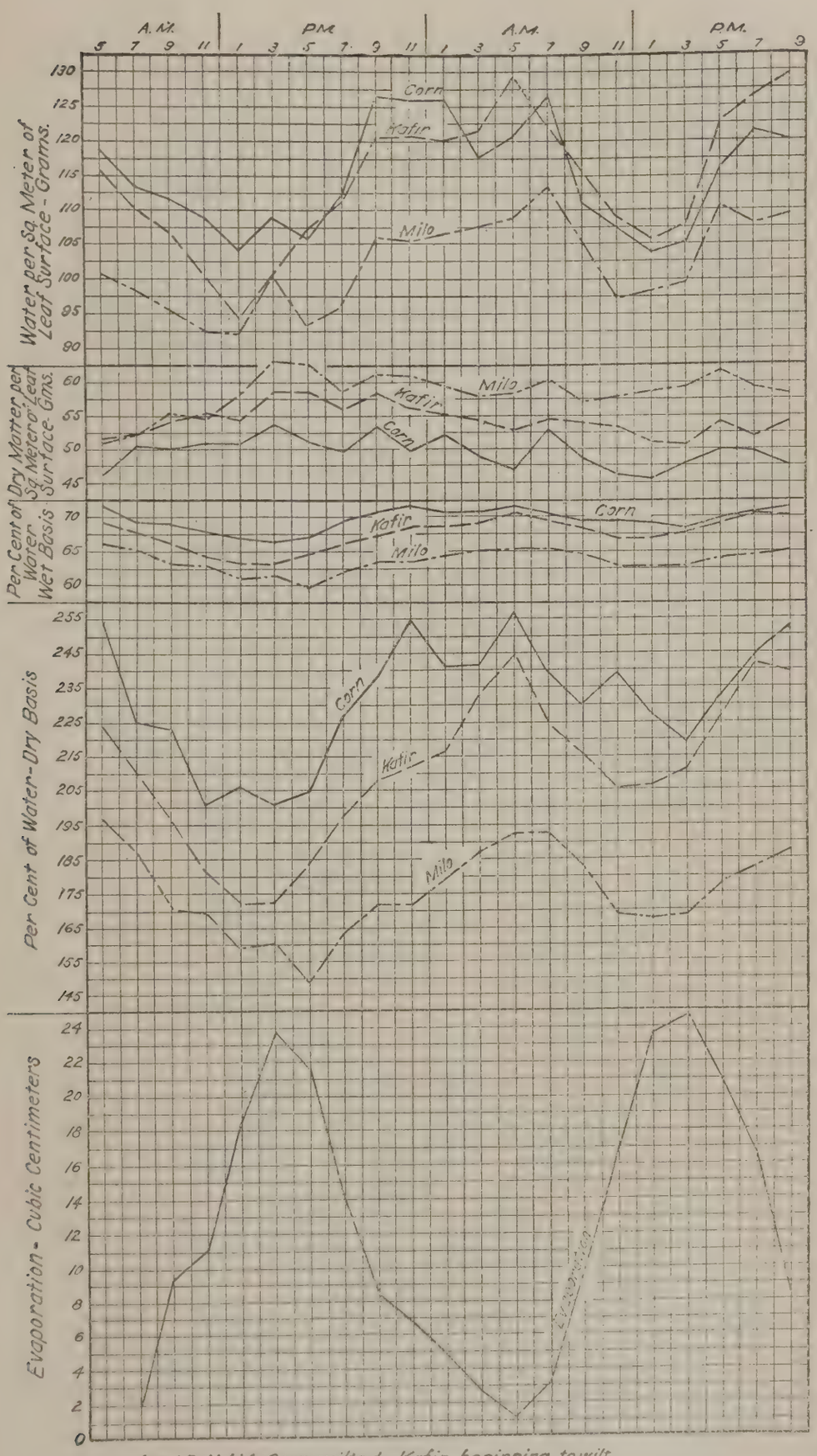


FIG. 3.—Graphs showing the amount of water and dry matter in the leaves of corn, kafir, and milo for August 10 and 11, 1914, and the evaporation for the corresponding period.


A.M.
P.M.
A.M.
P.M.
5 7 9 11 1 3 5 7 9 11 1 3 5 7 9 11 1 3 5 7 9
Water per Sq. Meter of Leaf Surface - Grams.
130 125 120 115 110 105 100 95 90
Corn
Kafir
Milo
Dry Matter per Sq. Meter of Leaf Surface - Gms.
60 55 50 45
Milo
Kafir
Corn
Per Cent of Water Wet Basis
70 65 60
Kafir
Corn
Milo
Per Cent of Water - Dry Basis
255 245 235 225 215 205 195 185 175 165 155 145
Corn
Kafir
Milo
Evaporation - Cubic Centimeters
24 22 20 18 16 14 12 10 8 6 4 2 0
Evaporation

Aug. 15 - 11 A.M. Corn wilted. Kafir beginning to wilt.
5 P.M. Leaves about normal. Milo did not wilt at all
Aug. 16 - 3 A.M. Guttation showing on kafir.
1 P.M. Corn and kafir wilted. Hot winds. Upper leaves of milo rolled a trifle.

FIG. 4. [illegible] showing the amount of water and dry matter in the leaves of corn, kafir, and milo for August 15 and 16, 1914, and the evaporation for the corresponding period.

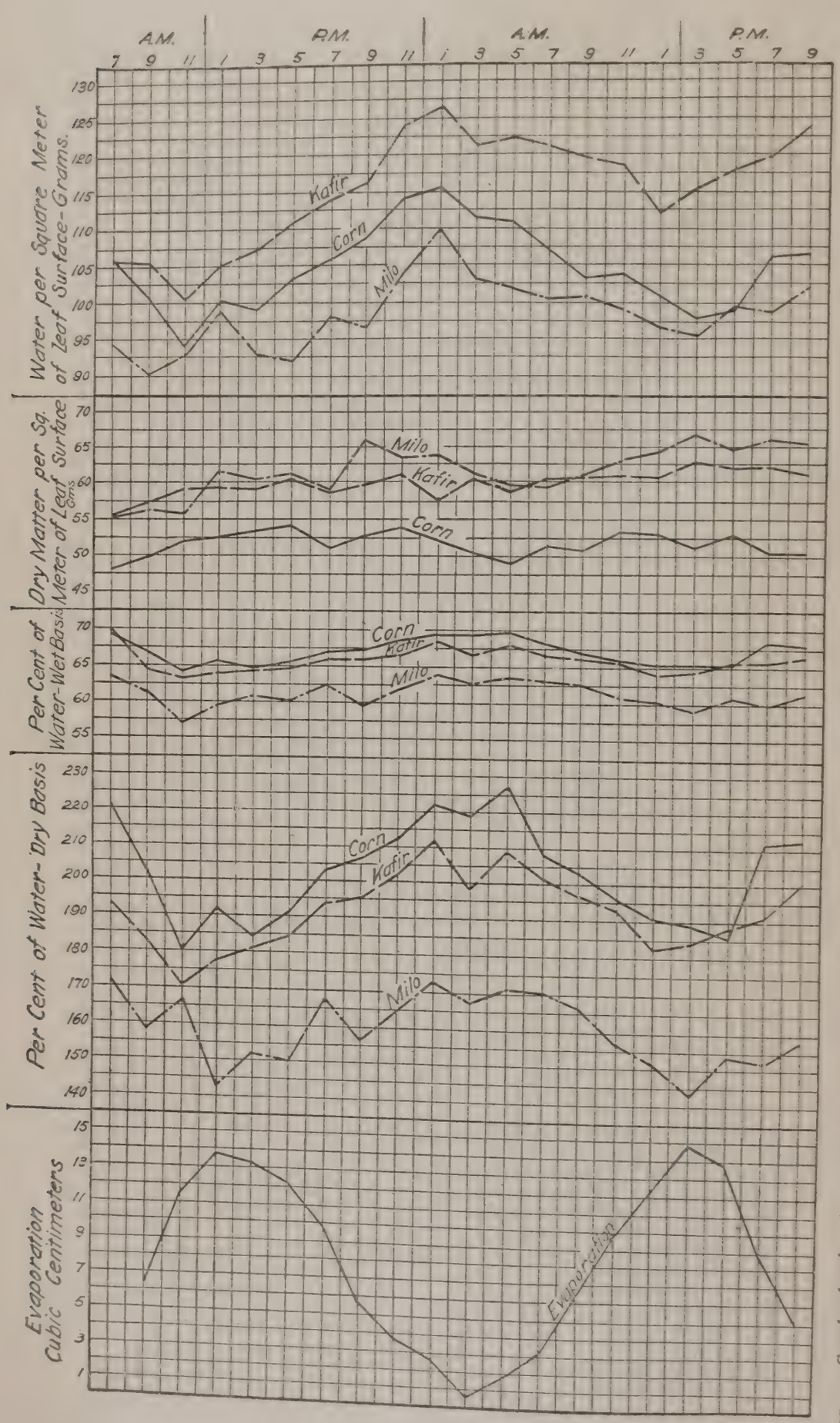


FIG. 5.—Graphs showing the amount of water and dry matter in the leaves of corn, kafir, and milo for August 25 and 26, 1914, and the evaporation for the corresponding period.

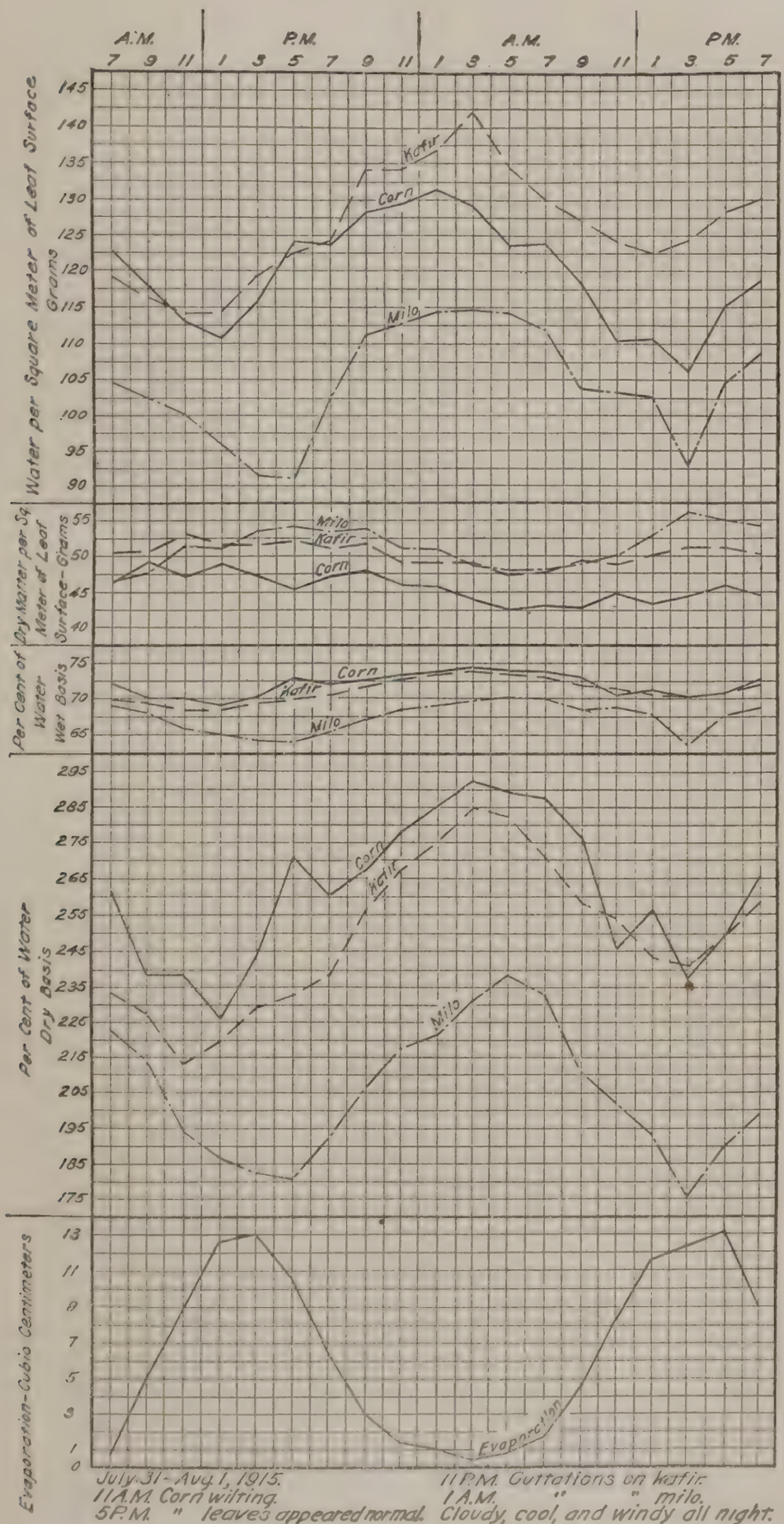

A.M.
P.M.
A.M.
P.M.
7 9 11 1 3 5 7 9 11 1 3 5 7 9 11 1 3 5 7
Water per Square Meter of Leaf Surface Grams
145 140 135 130 125 120 115 110 105 100 95 90
Kafir
Corn
Milo
Dry Matter per Sq. Meter of Leaf Surface-Grams
55 50 45 40
Milo
Kafir
Corn
Per Cent of Water Wet Basis
75 70 65
Corn
Kafir
Milo
Per Cent of Water Dry Basis
295 285 275 265 255 245 235 225 215 205 195 185 175
Corn
Kafir
Milo
Evaporation-Cubic Centimeters
13 11 9 7 5 3 1 0
Evaporation
July 31-Aug. 1, 1915.
11 A.M. Corn wilting.
5 P.M. " leaves appeared normal.
11 P.M. Guttations on kafir.
1 A.M. " " milo.
Cloudy, cool, and windy all night.

FIG. 6.—Graphs showing the amount of water and dry matter in the leaves of corn, kafir, and milo for July 13 and August 1, 1915, and the evaporation for the same period.

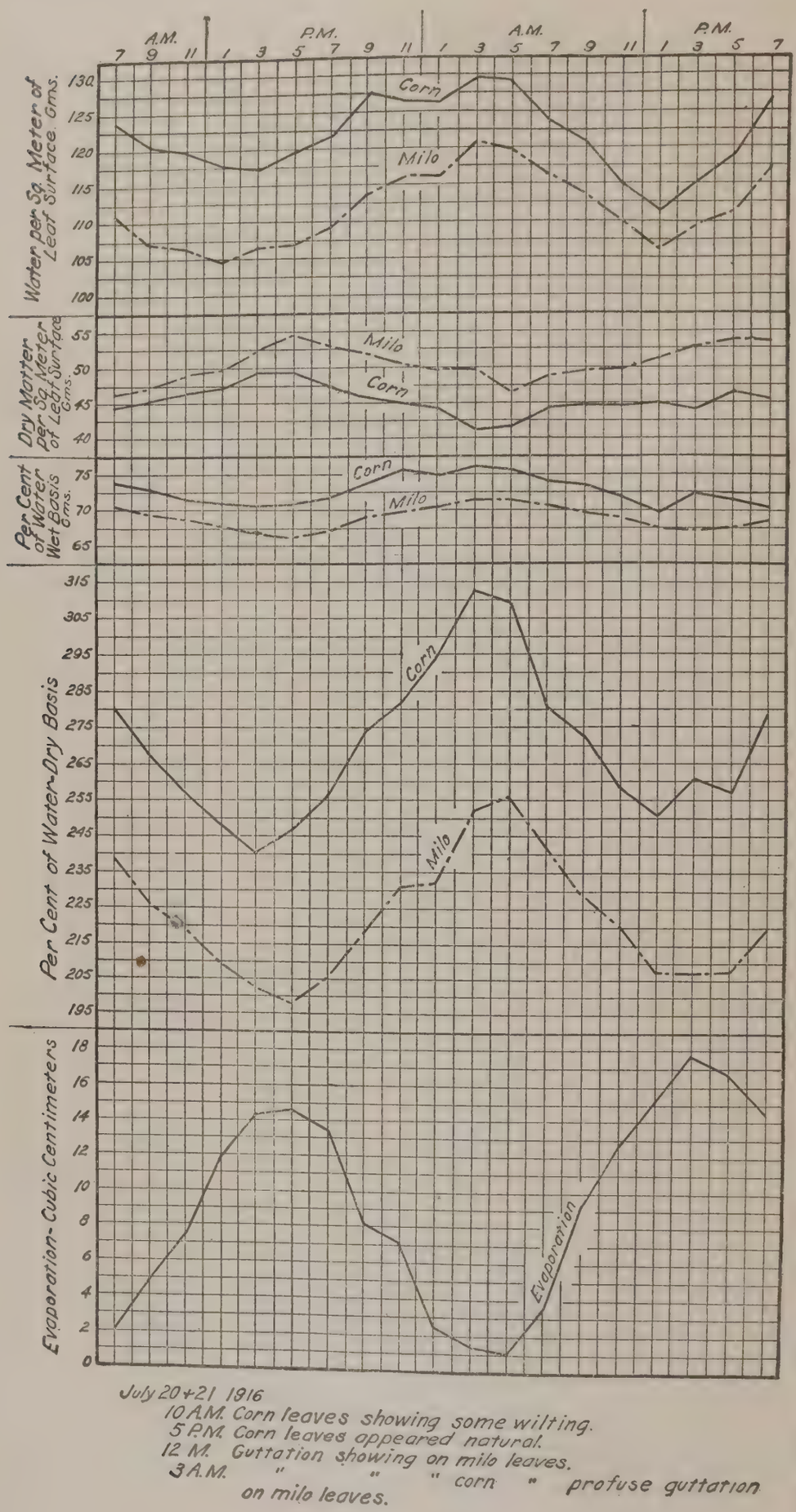

A.M.
P.M.
A.M.
P.M.
7 9 11 1 3 5 7 9 11 1 3 5 7 9 11 1 3 5 7
Water per Sq. Meter of Leaf Surface Gms.
130 125 120 115 110 105 100
Corn
Milo
Dry Matter per Sq. Meter of Leaf Surface Gms.
55 50 45 40
Milo
Corn
Per Cent of Water Wet Basis Gms.
75 70 65
Corn
Milo
Per Cent of Water-Dry Basis
315 305 295 285 275 265 255 245 235 225 215 205 195
Corn
Milo
Evaporation-Cubic Centimeters
18 16 14 12 10 8 6 4 2 0
Evaporation
July 20+21 1916
10 A.M. Corn leaves showing some wilting.
5 P.M. Corn leaves appeared natural.
12 M. Guttation showing on milo leaves.
3 A.M. " " " corn " profuse guttation on milo leaves.

FIG. 7.—Graphs showing the amount of water and dry matter in the leaves of corn and milo for July 20 and 21, 1916, and the evaporation for the corresponding period.

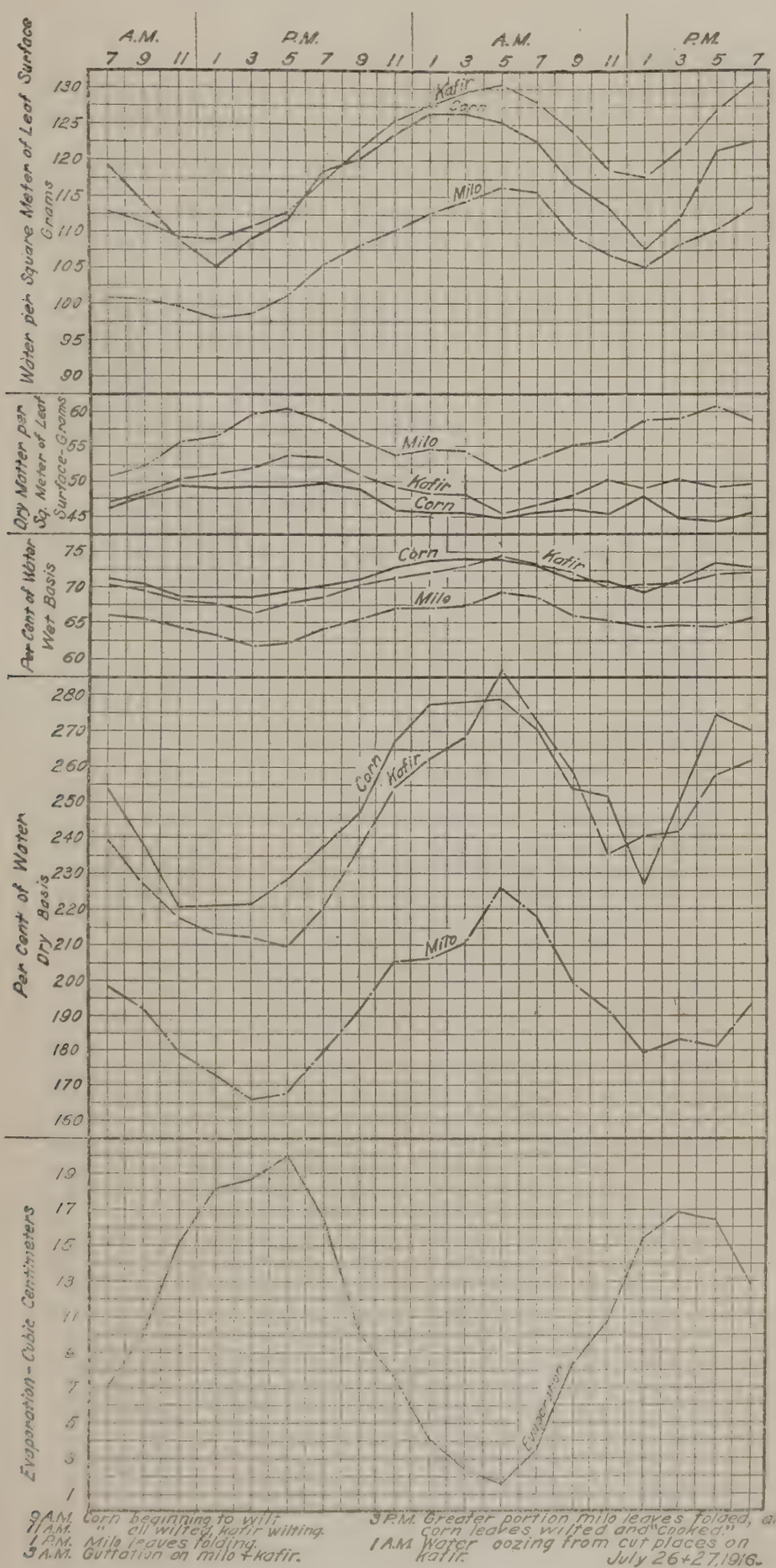


FIG. 8.—Graphs showing the amount of water in the leaves of corn, kafir, and milo for July 26 and 27 1916, and the evaporation for the corresponding period.

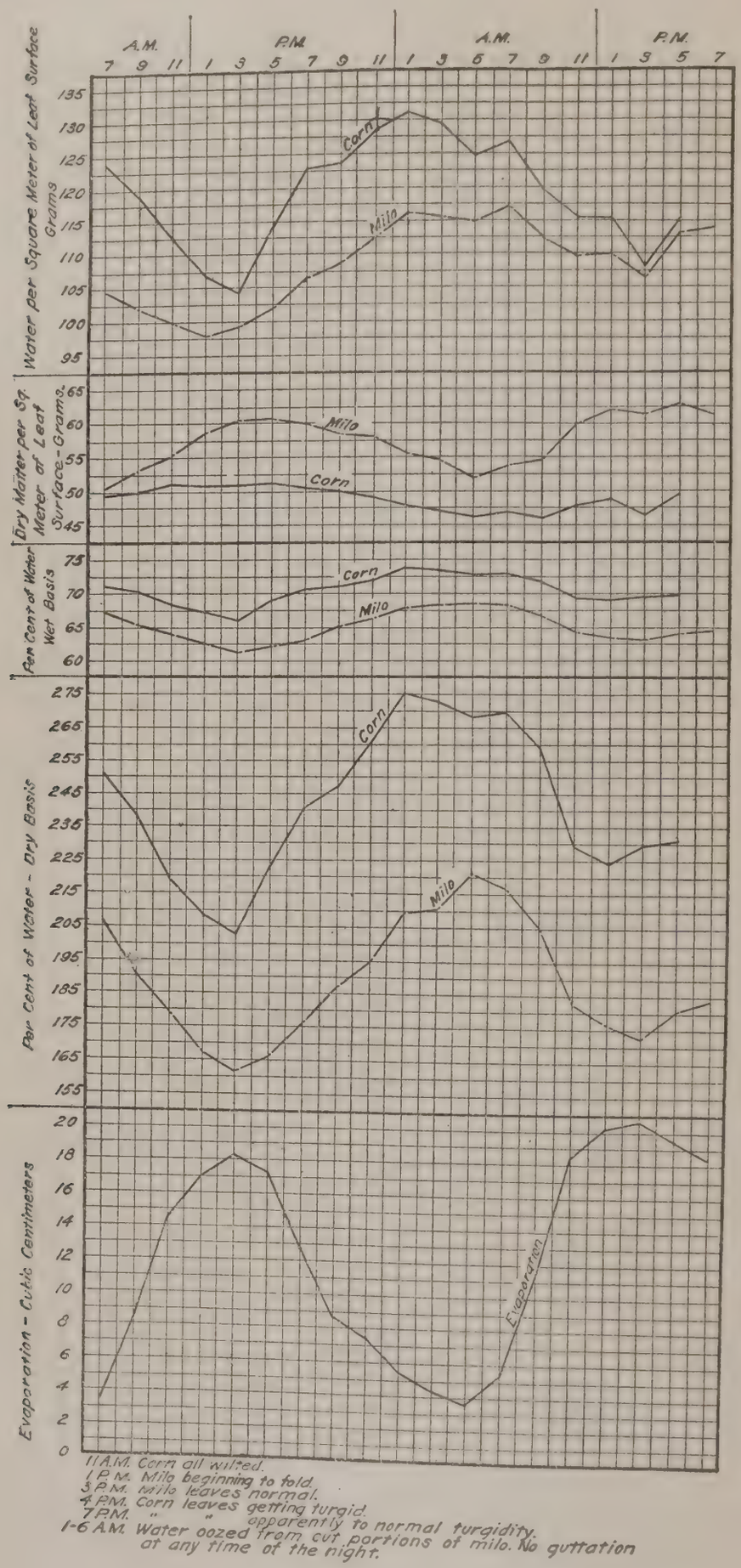

A.M.
P.M.
A.M.
P.M.
7 9 11 1 3 5 7 9 11 1 3 5 7 9 11 1 3 5 7
Water per Square Meter of Leaf Surface Grams
135 130 125 120 115 110 105 100 95
Corn
Milo
Dry Matter per Sq Meter of Leaf Surface-Grams
65 60 55 50 45
Milo
Corn
Per Cent of Water Wet Basis
75 70 65 60
Corn
Milo
Per Cent of Water - Dry Basis
275 265 255 245 235 225 215 205 195 185 175 165 155
Corn
Milo
Evaporation - Cubic Centimeters
20 18 16 14 12 10 8 6 4 2 0
Evaporation
11 A.M. Corn all wilted.
1 P.M. Milo beginning to fold.
3 P.M. Milo leaves normal.
4 P.M. Corn leaves getting turgid.
7 P.M. " " apparently to normal turgidity.
1-6 A.M. Water oozed from cut portions of milo. No guttation at any time of the night.

FIG. 9.—Graphs showing the amount of water in the leaves of corn and milo for August 1 and 2, 1916, and the evaporation for the corresponding period.

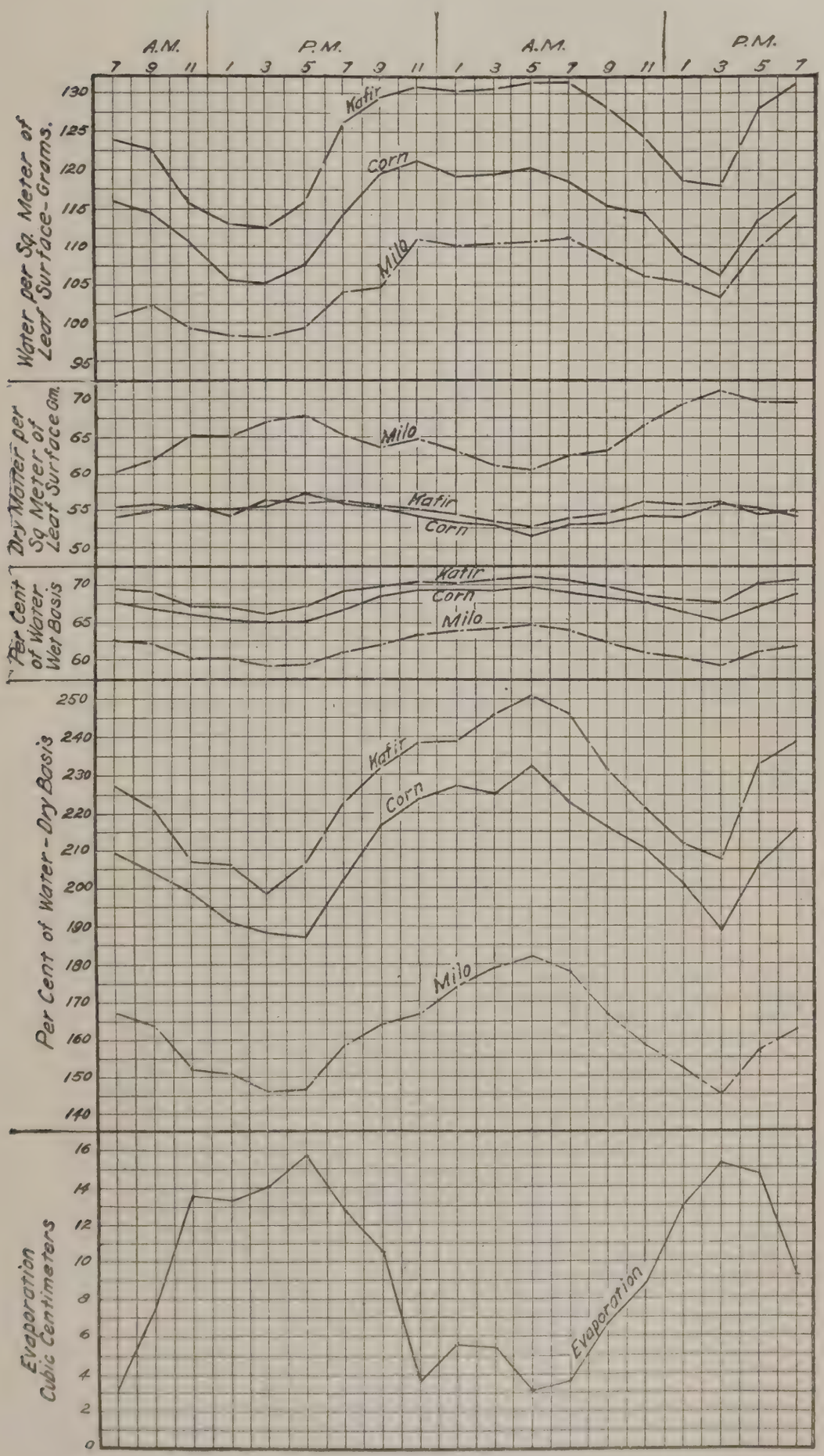


FIG. 10.—Graphs showing the amount of water in the leaves of corn, kafir, and milo for August 10 and 11, 1916, with the evaporation for the corresponding period.

TABLE III.—*Variation of the water and dry matter in the leaves of Pride of Saline corn, Blackhull kafir, and Dwarf milo at Garden City, Kans.*

JUNE 24 AND JULY 9, 1914

Period ending—	Water in 30 samples.			Dry matter in 30 samples.			Water per square meter of leaf.			Dry matter per square meter of leaf.			Percentage of water, wet basis.			Percentage of dry matter.			Percentage of water, dry basis.		
	Corn.	Kafir.	Milo.	Corn.	Kafir.	Milo.	Corn.	Kafir.	Milo.	Corn.	Kafir.	Milo.	Corn.	Kafir.	Milo.	Corn.	Kafir.	Milo.	Corn.	Kafir.	Milo.
June 24:	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*									
7 a. m.	476.6	403.6	378.0	95.4	85.4	96.0	158.8	134.5	126.0	31.8	28.5	32.0	83.3	82.5	79.5	16.7	17.5	20.5	499.2	472.2	393.6
9 a. m.	434.6	385.4	362.6	102.8	88.0	103.7	144.9	128.5	120.9	34.3	29.9	34.6	80.8	81.4	77.7	19.2	18.6	22.3	422.7	437.7	349.6
11 a. m.	427.4	371.8	359.8	110.4	100.6	106.2	142.5	124.9	119.9	36.8	33.5	35.4	79.4	78.8	77.2	20.6	21.2	22.8	387.1	372.5	338.7
1 p. m.	444.8	386.4	363.4	107.0	98.6	100.0	148.3	128.8	121.3	35.7	32.9	33.3	80.6	79.6	78.4	19.4	20.4	21.6	415.7	391.8	363.4
3 p. m.	443.0	384.4	355.2	109.8	113.4	121.6	147.7	128.1	118.4	36.6	37.8	40.5	80.1	77.2	74.4	19.9	22.8	25.6	403.4	338.9	292.1
5 p. m.	450.0	386.6	333.0	113.4	114.6	126.4	150.0	128.9	111.0	37.8	38.3	42.1	79.8	77.1	72.4	20.2	22.9	27.6	396.8	337.6	233.4
7 p. m.	461.7	397.0	366.2	105.4	108.4	111.6	153.9	132.3	122.0	35.1	36.1	37.2	81.4	78.5	76.6	18.6	21.5	23.4	438.0	366.2	328.1
July 9:																					
7 a. m.	389.2	388.2	339.5	127.2	136.4	149.6	129.7	129.4	113.2	42.4	45.7	49.9	75.3	73.9	69.4	24.7	26.1	30.6	305.9	284.6	226.9
9 a. m.	366.0	371.6	332.2	142.2	142.8	154.4	122.0	123.8	110.7	47.4	47.6	51.5	72.0	72.2	68.2	28.0	27.8	31.8	257.3	260.2	215.1
11 a. m.	379.2	375.2	325.4	130.2	143.0	161.2	126.4	125.1	108.5	43.4	47.7	53.7	74.4	72.4	66.8	25.6	27.6	33.2	291.2	262.3	201.8
1 p. m.	370.4	374.6	326.0	145.0	141.8	165.3	123.5	124.9	108.7	48.3	47.3	55.1	71.8	72.5	66.3	28.2	27.5	33.7	255.4	264.1	197.2
3 p. m.	374.2	368.4	319.2	150.6	150.4	169.2	124.7	122.8	106.4	50.2	50.1	56.4	71.3	71.0	65.3	28.7	29.0	34.7	248.4	244.9	188.6
5 p. m.	364.2	376.5	331.4	152.8	151.5	164.4	121.4	125.5	110.5	50.9	50.5	54.8	70.4	71.3	66.8	29.6	28.7	33.2	238.3	248.5	201.5
7 p. m.	389.4	386.4	335.8	140.8	143.4	161.6	129.8	128.8	111.9	46.9	47.8	53.9	73.4	72.9	67.4	26.6	27.1	32.6	276.5	269.4	207.7
9 p. m.	406.2	399.0	355.0	136.8	144.0	163.0	135.4	133.0	118.3	45.6	48.7	54.3	74.8	73.4	68.5	25.2	26.6	31.5	296.9	277.0	217.7

JULY 13 AND 22, 1914

July 13:																					
7 a. m.	397.4	372.9	346.0	130.9	132.9	138.4	132.5	120.2	115.3	43.6	44.3	46.1	75.2	73.7	71.4	24.8	26.3	28.6	303.5	280.5	250.0
9 a. m.	388.4	360.6	340.6	132.6	135.9	141.2	129.5	120.2	113.5	44.2	45.3	47.1	74.5	72.6	70.6	25.5	27.4	29.4	292.9	265.3	241.2
11 a. m.	371.0	357.2	329.8	137.4	140.4	147.8	123.7	119.1	109.9	45.8	46.8	49.3	72.9	71.7	69.0	27.1	28.3	31.0	270.0	254.4	223.1
1 p. m.	372.6	352.6	321.0	143.4	144.7	155.6	124.2	117.5	107.0	47.8	48.2	51.9	72.2	70.9	67.3	27.8	29.1	32.7	259.8	243.6	206.2
3 p. m.	378.6	355.8	327.6	142.0	146.6	156.2	126.2	118.6	109.2	47.3	48.9	52.1	72.7	70.8	67.7	27.3	29.2	32.3	266.6	242.7	209.7
5 p. m.	377.8	365.2	335.0	146.4	150.8	161.0	125.9	121.7	111.7	48.8	50.3	53.7	72.0	70.7	67.5	28.0	29.3	32.5	258.0	242.1	208.0
7 p. m.	394.4	375.8	353.0	141.7	143.4	158.0	131.5	125.3	117.7	47.2	47.8	52.7	73.5	72.3	69.0	26.5	27.7	31.0	278.3	262.0	223.4
9 p. m.	406.6	390.8	366.6	136.6	140.4	152.6	135.5	130.3	122.2	45.5	46.8	50.7	74.8	73.5	70.6	25.2	26.5	29.4	297.6	278.3	240.2
11 p. m.	405.0	405.4	391.4	130.2	138.2	147.8	135.0	135.1	130.5	43.4	46.1	49.3	75.6	74.5	72.5	24.4	25.5	27.5	317.0	293.3	264.8
July 22:																					
7 a. m.	376.8	356.6	336.4	136.2	147.4	165.8	125.6	118.9	112.1	45.4	49.1	55.3	73.4	70.7	67.0	26.6	29.3	33.0	276.6	241.9	202.8
9 a. m.	369.2	350.2	324.4	140.8	152.4	161.0	123.1	116.7	108.1	46.9	50.8	53.7	72.3	69.6	66.8	27.7	30.4	33.2	262.2	229.7	201.4
11 a. m.	356.8	340.8	314.8	147.6	155.6	154.4	118.9	113.6	104.9	49.2	51.9	51.5	70.7	68.6	67.0	29.3	31.4	33.0	241.7	219.0	203.8
1 p. m.	359.4	328.8	315.2	152.6	158.6	172.8	119.8	109.6	105.1	50.9	52.9	57.6	70.1	67.4	64.5	29.9	32.6	35.5	235.5	207.3	182.4
3 p. m.	.....	334.8	312.8	150.4	161.4	179.8	.....	111.6	104.3	50.1	53.8	59.9	.....	67.4	63.4	.....	32.6	36.6	.....	207.4	173.9
5 p. m.	376.8	339.4	324.2	153.4	159.2	173.2	125.6	113.1	108.1	51.1	53.1	57.7	71.0	68.0	65.1	29.0	32.0	34.9	245.6	213.1	187.1
7 p. m.	367.8	356.8	350.4	143.0	157.8	173.4	122.6	118.9	116.8	47.7	52.6	57.8	72.0	69.3	66.8	28.0	30.7	33.2	257.2	226.1	202.0
9 a. m.	413.6	380.8	373.8	145.6	158.8	178.6	137.9	126.9	124.6	48.5	52.9	59.5	73.9	70.5	67.7	26.1	29.5	32.3	284.0	239.7	209.2

JULY 28 AND 29, 1914

July 28:																				
7 a. m.	387.0	354.6	344.8	119.6	129.4	138.2	129.0	118.2	114.9	39.9	43.1	46.1	76.3	73.2	71.3	23.7	26.8	28.7	323.5	274.0	249.4
9 a. m.	372.2	341.4	323.0	122.4	127.8	141.0	124.1	113.8	107.7	40.8	42.6	47.0	75.2	72.7	69.6	24.8	27.3	30.4	304.0	267.1	229.0
11 a. m.	351.8	329.8	320.0	125.8	132.4	147.0	117.3	109.9	106.7	41.9	40.8	49.0	73.6	71.3	68.5	26.4	28.7	31.5	279.6	249.0	217.6
1 p. m.	340.8	320.4	316.2	125.6	130.2	152.2	113.6	106.8	105.4	41.9	43.4	50.7	73.0	71.1	67.5	27.0	28.9	32.5	271.3	246.0	207.7
3 p. m.	337.2	324.2	322.2	124.8	130.4	157.0	112.4	108.1	107.4	41.6	43.1	52.3	72.9	71.3	67.2	27.1	28.7	32.8	270.1	248.5	205.2
5 p. m.	356.6	330.2	323.2	129.4	133.8	157.4	118.9	110.1	107.7	43.1	44.6	52.5	73.3	71.1	67.2	26.7	28.9	32.8	275.5	246.7	205.3
7 p. m.	381.2	350.6	344.4	124.6	134.0	158.2	127.1	116.9	114.8	41.5	44.7	52.7	75.3	72.3	66.5	24.7	27.7	33.5	305.9	261.6	217.6
9 p. m.	404.6	361.2	372.8	123.2	130.0	152.8	134.9	120.4	124.3	41.1	43.3	50.9	76.6	73.5	70.9	23.4	26.5	29.1	328.4	277.8	243.9
11 p. m.	417.6	378.0	390.6	117.6	128.6	156.2	139.2	126.2	130.2	39.2	42.9	52.1	78.0	74.6	71.9	22.0	25.4	28.1	355.1	294.4	250.0
July 29:																					
1 p. m.	407.8	389.6	373.8	115.6	127.2	145.4	135.9	129.2	124.6	38.5	42.4	48.5	77.9	75.4	71.9	22.1	24.6	28.1	352.7	306.2	257.0
3 a. m.	415.8	390.8	370.4	105.2	117.6	136.4	138.6	130.3	123.5	35.1	39.2	45.4	79.8	76.8	73.0	20.2	23.2	27.0	395.2	332.3	271.5
5 a. m.	416.2	388.8	385.8	99.6	110.0	132.6	138.7	129.6	128.6	33.2	36.7	44.2	80.6	77.9	74.4	19.4	22.1	25.6	417.8	353.4	290.9

AUGUST 3 AND 4, 1914

August 3:																				
7 a. m.	356.2	345.4	314.2	149.0	171.6	182.2	118.7	115.1	104.7	49.7	57.2	60.7	70.5	66.8	63.2	29.5	33.2	36.8	239.0	201.2	172.4
9 a. m.	329.0	335.8	298.4	164.8	181.0	183.2	109.7	111.9	99.5	54.9	60.3	61.1	66.6	64.7	61.9	33.4	35.3	38.1	199.6	185.5	162.8
11 a. m.	329.2	334.2	295.4	162.4	181.4	188.8	109.7	111.4	98.5	53.1	60.5	61.9	66.9	64.8	61.0	33.1	35.2	39.0	202.7	184.2	156.4
1 p. m.	329.6	322.4	287.0	161.2	187.8	199.6	109.9	107.5	99.0	50.4	62.6	66.5	67.1	63.1	58.9	32.9	36.9	41.1	204.4	171.6	143.7
3 p. m.	307.4	333.4	286.4	160.4	184.4	199.4	102.5	111.1	95.5	53.5	61.5	66.5	65.7	64.3	58.9	34.3	35.7	41.1	191.6	180.8	143.6
5 p. m.	321.0	343.6	299.2	161.4	190.8	203.0	107.0	114.5	99.7	53.8	63.6	67.0	66.5	64.2	59.5	33.5	35.8	40.5	198.8	180.0	147.3
7 p. m.	342.0	354.2	300.2	256.0	187.4	200.8	114.0	118.1	100.1	52.0	62.5	66.9	68.6	65.3	59.9	31.4	34.7	40.1	219.2	189.0	149.5
9 p. m.	346.4	365.0	312.6	161.2	188.8	202.6	115.5	121.7	104.2	53.7	62.9	67.5	68.2	65.9	60.6	31.8	34.1	39.4	214.8	194.1	154.2
11 p. m.	370.8	369.2	326.5	160.8	179.8	198.1	123.6	123.1	108.8	53.6	59.9	66.0	69.7	67.3	62.2	30.3	32.7	37.8	230.5	205.3	164.8
August 4:																					
1 a. m.	379.6	398.0	343.0	160.8	190.2	205.6	126.5	132.7	114.3	53.6	63.4	68.5	70.2	67.6	62.5	29.8	32.4	37.5	236.0	209.2	164.8
3 a. m.	362.2	378.0	330.6	149.4	183.2	188.8	120.7	126.0	110.2	49.8	61.1	62.9	70.7	67.3	63.6	29.3	32.7	36.4	242.4	206.3	166.8
5 a. m.	354.4	388.2	342.2	145.4	175.3	185.0	118.1	129.4	114.1	48.5	58.4	61.7	70.9	70.1	63.9	29.1	29.9	35.1	243.7	221.4	184.9
7 a. m.	342.0	379.0	324.0	147.0	179.6	184.4	114.0	126.3	108.0	49.0	59.9	61.5	69.9	67.1	63.7	30.1	32.9	36.3	232.6	211.0	175.7
9 a. m.	369.2	384.4	335.6	166.6	190.0	200.4	123.1	128.3	111.9	55.5	63.3	66.8	68.9	66.9	62.2	31.1	33.1	37.4	221.6	202.5	167.4
11 a. m.	369.8	381.6	326.8	166.4	191.2	209.6	123.2	127.2	108.9	55.5	63.7	69.9	68.8	66.6	60.9	31.2	33.4	39.1	222.2	199.5	155.9
1 p. m.	359.8	302.0	156.8	190.2	212.6	.....	119.9	100.7	52.3	63.4	70.9	.....	65.4	58.7	.....	34.6	41.3	.....	188.8	142.0	

TABLE III.—*Variation of the water and dry matter in the leaves of Pride of Saline corn, Blackhull kafir, and Dwarf milo at Garden City, Kans.*—Con.

AUGUST 10 AND 11, 1914

Period ending—	Water in 30 samples.			Dry matter in 30 samples.			Water per square meter of leaf.			Dry matter per square meter of leaf.			Percentage of water, wet basis.			Percentage of dry matter.			Percentage of water, dry basis.		
	Corn.	Kafir.	Milo.	Corn.	Kafir.	Milo.	Corn.	Kafir.	Milo.	Corn.	Kafir.	Milo.	Corn.	Kafir.	Milo.	Corn.	Kafir.	Milo.	Corn.	Kafir.	Milo.
	Mgm.	*Mgm.*	*Mgm.*	*Mgm.*	*Mgm.*	*Mgm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*									
August 10:																					
5 a. m.	360.0	354.8	324.8	133.8	146.8	154.4	120.0	118.3	108.3	44.6	48.9	51.5	72.9	70.7	67.7	27.1	29.3	32.3	269.0	241.6	210.3
7 a. m.	354.6	344.6	306.4	140.0	152.8	156.8	118.2	114.9	102.2	46.7	50.9	52.2	71.6	69.2	66.1	28.4	30.8	33.9	253.6	225.5	195.6
9 a. m.	354.2	356.0	314.0	145.4	155.6	165.2	118.1	118.7	104.7	48.5	51.9	55.1	70.8	69.5	65.5	29.2	30.5	34.5	243.6	228.7	190.0
11 a. m.	339.0	333.2	300.2	150.0	158.8	169.0	113.0	110.7	100.7	50.0	52.9	56.3	69.3	67.7	63.9	30.7	32.3	36.1	226.0	209.8	177.6
1 p. m.	328.8	331.0	302.0	154.4	166.0	180.0	109.6	110.3	100.7	51.5	55.3	60.0	68.0	66.5	62.6	32.0	33.5	37.4	212.9	199.3	167.7
3 p. m.	338.2	334.2	303.6	150.2	166.2	181.0	112.7	111.4	101.2	50.1	55.4	60.3	69.2	66.7	62.6	30.8	33.3	37.4	225.1	201.0	167.7
5 p. m.	330.8	342.0	310.6	147.2	166.8	184.0	110.3	114.0	103.5	49.1	55.6	61.3	69.2	67.2	62.7	30.8	32.8	37.3	224.7	205.0	168.8
7 p. m.	354.8	343.0	307.2	145.2	160.2	179.8	118.3	114.3	102.4	48.4	53.4	59.9	70.9	68.1	63.0	29.1	31.9	37.0	244.3	214.1	170.8
9 p. m.	369.0	362.4	323.0	140.8	152.8	169.0	123.0	120.8	107.7	46.9	50.9	56.3	72.3	70.3	65.6	27.7	29.7	34.4	262.0	237.1	191.1
11 p. m.	400.6	389.6	350.8	145.8	155.8	173.6	133.5	129.9	116.9	48.6	51.9	57.9	73.3	71.4	66.8	26.7	28.6	33.1	274.7	250.0	202.0
August 11:																					
1 a. m.	392.4	412.2	362.6	139.4	152.4	173.8	130.8	137.4	120.9	46.5	50.8	57.9	73.7	73.0	67.5	26.3	27.0	32.5	281.4	270.4	208.6
3 a. m.	370.0	382.4	346.7	132.4	145.2	165.7	123.5	127.5	115.6	44.1	48.4	55.2	73.6	72.4	67.6	26.4	27.6	32.4	279.4	263.3	209.2
5 a. m.	360.4	368.4	336.2	131.6	140.4	156.2	120.1	122.8	112.1	43.9	46.8	52.1	73.2	72.4	68.2	26.8	27.6	31.8	273.8	262.3	215.2
7 a. m.	370.6	365.4	333.8	138.2	146.6	165.0	123.5	121.9	111.3	46.1	48.9	55.0	72.8	71.3	66.9	27.2	28.7	33.1	268.1	249.5	202.3
9 a. m.	353.8	364.8	324.0	137.0	151.4	169.0	117.9	121.6	108.9	45.7	50.5	56.3	72.0	70.6	65.7	28.0	29.4	34.3	258.2	240.9	191.7
11 a. m.	350.8	351.8	320.2	139.4	149.4	172.6	116.9	117.3	106.7	46.5	49.4	57.7	71.5	70.1	65.0	28.5	29.9	35.0	251.6	235.4	185.9
1 p. m.	366.2	379.8	347.6	147.8	154.0	181.0	122.1	126.6	112.5	49.3	51.3	60.3	71.2	71.1	65.7	28.8	28.9	34.3	247.7	246.6	192.0
3 p. m.	392.6	374.8	360.0	137.4	144.4	171.6	130.9	124.9	120.0	45.8	48.1	57.2	74.0	72.1	67.7	26.0	27.9	32.3	285.7	259.5	209.7

AUGUST 15 AND 16, 1914

August 15:																					
5 a. m.	356.0	349.4	303.4	139.6	155.6	153.8	118.7	116.5	101.3	46.5	51.9	51.3	71.8	69.1	66.3	28.2	30.9	33.7	255.0	224.5	197.2
7 a. m.	339.8	331.6	294.2	151.0	157.2	157.2	113.3	110.5	98.1	50.3	52.4	52.4	69.2	67.8	65.1	30.8	32.2	34.9	225.0	210.9	187.1
9 a. m.	335.0	320.6	285.8	150.2	162.0	166.8	111.7	106.9	95.3	50.1	54.0	55.6	69.0	66.4	63.1	31.0	33.6	36.9	223.0	196.9	171.3
11 a. m.	324.4	301.2	277.6	152.8	165.8	163.8	108.1	100.4	92.5	50.9	55.3	54.6	67.9	64.4	62.8	32.1	35.6	37.2	200.4	181.6	169.4
1 p. m.	313.2	282.6	276.0	152.6	163.8	174.0	104.4	94.2	92.0	50.9	54.6	58.0	67.2	63.3	61.3	32.8	36.7	38.7	205.2	172.5	158.6
3 p. m.	324.4	302.2	303.8	161.8	174.8	189.2	108.1	100.7	101.3	53.9	58.3	63.1	66.7	63.3	61.6	33.3	36.7	38.4	200.4	172.8	160.5
5 p. m.	317.2	322.0	280.0	154.8	175.0	188.4	105.7	107.3	93.3	51.6	58.3	62.8	67.2	64.7	59.7	32.8	35.3	40.3	204.9	184.0	148.6
7 p. m.	337.2	334.6	288.9	149.0	169.2	176.4	112.4	111.5	96.3	49.7	56.4	58.8	69.3	66.4	62.0	30.7	33.6	38.0	226.3	197.7	163.7
9 p. m.	380.8	361.4	318.2	159.6	174.2	184.8	126.7	120.5	106.1	53.2	58.1	61.6	70.4	67.4	63.2	29.6	32.6	36.8	238.5	207.4	172.1
11 p. m.	378.2	362.6	316.0	148.4	169.8	183.8	126.1	120.9	105.3	49.5	56.6	61.3	71.8	68.1	63.2	28.2	31.9	36.8	254.8	213.5	171.9

August 16:																				
1 a. m.	378.4	360.3	318.8	157.0	166.6	177.6	126.1	120.0	106.3	52.3	55.5	59.2	70.6	68.3	64.2	29.4	31.7	35.8	241.0	216.0	179.5
3 a. m.	352.4	365.8	322.6	146.0	163.6	173.0	117.5	121.9	107.5	48.7	54.3	57.7	70.7	69.0	65.0	29.3	31.0	35.0	241.3	233.5	186.4
5 a. m.	362.2	388.2	326.4	141.4	158.6	174.0	120.7	129.4	108.8	47.1	52.9	58.9	71.9	70.7	65.2	28.1	29.3	34.8	256.1	244.7	187.5
7 a. m.	379.8	366.4	339.6	158.6	163.0	181.0	126.6	122.1	113.2	52.9	54.3	60.3	70.5	69.2	65.2	29.5	30.8	34.8	239.4	224.7	187.6
9 a. m.	335.2	347.8	315.2	145.8	161.6	171.6	111.7	115.9	105.1	48.6	53.9	57.2	69.6	68.2	64.7	30.4	31.8	35.3	229.9	215.2	183.6
11 a. m.	322.0	326.6	291.6	139.4	159.2	173.0	107.4	108.9	97.2	46.4	53.1	57.7	69.7	67.2	62.7	30.3	32.8	37.3	239.4	205.1	168.5
1 p. m.	311.2	316.6	293.6	136.8	153.6	175.2	103.7	105.5	97.9	45.6	51.2	58.4	69.4	67.3	62.6	30.6	32.7	37.4	227.4	206.1	167.5
3 p. m.	315.8	323.4	299.5	144.0	153.0	178.0	105.3	107.8	99.8	48.0	51.0	59.3	68.6	67.8	62.7	31.4	32.2	37.3	219.3	211.3	168.2
5 p. m.	350.2	368.8	332.0	150.0	162.4	186.2	116.7	122.9	110.7	50.0	54.1	62.1	70.0	69.4	64.0	30.0	30.6	36.0	233.4	227.0	178.3
7 p. m.	365.4	380.0	324.6	149.2	156.6	177.8	121.8	126.7	108.2	49.7	52.2	59.3	71.0	70.8	64.6	29.0	29.2	35.4	244.9	242.5	182.5
9 p. m.	360.6	389.0	328.6	142.6	162.2	175.4	120.2	129.7	109.5	47.5	54.1	58.5	71.6	70.5	65.1	28.4	29.5	34.9	252.8	239.8	187.3

AUGUST 25 AND 26, 1914

August 25:																				
7 a. m.	319.6	318.4	283.2	143.4	167.2	165.0	106.5	106.1	94.4	47.8	55.7	55.0	69.0	69.8	63.1	31.0	30.2	36.9	222.8	193.9	171.6
9 a. m.	305.4	316.8	271.0	149.7	172.2	170.2	101.8	105.6	90.3	49.9	57.4	56.7	67.1	64.7	61.4	32.9	35.2	38.6	204.0	183.9	159.2
11 a. m.	282.7	301.8	278.4	156.8	177.4	168.0	94.0	100.6	92.8	52.3	59.1	56.0	64.3	62.9	57.2	35.7	37.1	42.8	180.2	170.1	165.7
1 p. m.	302.0	315.6	265.6	157.6	178.0	185.4	100.7	105.2	98.5	52.5	59.3	61.8	65.7	63.9	58.9	34.3	36.1	41.1	191.6	177.3	143.2
3 p. m.	294.2	321.0	278.4	159.8	178.0	182.8	98.1	107.0	92.8	53.3	59.3	60.9	64.8	64.3	60.3	35.2	35.7	39.7	184.7	180.3	152.2
5 p. m.	310.4	334.4	276.4	163.0	181.2	184.0	103.1	111.5	92.1	54.3	60.4	61.3	65.5	64.8	60.0	34.5	35.2	40.0	190.4	184.5	150.2
7 p. m.	317.4	341.4	293.4	155.8	176.0	176.2	105.8	113.8	97.8	51.9	58.7	58.7	67.0	65.9	62.4	33.0	34.1	37.6	203.7	193.9	166.5
9 p. m.	324.8	349.4	290.6	157.8	179.0	196.2	108.3	116.5	96.9	52.6	59.7	65.4	67.3	66.1	59.6	32.7	33.9	40.4	205.8	195.1	156.0
11 p. m.	340.6	370.4	311.8	161.0	184.0	189.6	113.5	123.5	103.9	53.7	61.3	63.2	67.9	66.8	62.1	32.1	33.2	37.9	211.5	201.3	164.6
August 26:																				
1 a. m.	347.8	380.4	329.2	157.2	179.2	190.0	115.9	126.8	109.7	52.4	57.7	63.3	68.8	67.9	63.4	31.2	32.1	36.6	221.3	212.2	173.2
3 a. m.	335.2	365.0	308.4	152.4	181.4	184.2	111.7	121.7	102.8	50.8	60.5	61.4	68.7	66.8	62.6	31.3	33.2	37.4	219.9	198.3	167.4
5 a. m.	333.0	366.4	306.2	146.6	175.0	179.4	111.0	122.1	102.1	48.9	58.3	59.8	69.4	67.6	63.0	30.6	32.4	37.0	227.1	209.3	170.6
7 a. m.	321.4	364.0	301.4	154.0	181.0	177.2	107.1	121.3	100.5	51.3	60.3	59.1	67.6	66.7	62.9	32.4	33.3	37.1	208.7	201.1	170.2
9 a. m.	308.8	357.2	302.2	152.0	182.0	182.6	102.9	119.1	100.7	50.7	60.7	60.9	67.0	66.2	62.5	33.0	33.8	37.5	203.1	196.2	165.4
11 a. m.	310.4	354.0	295.2	158.8	182.8	188.4	103.5	118.0	98.4	52.9	60.9	62.8	66.1	65.9	61.0	33.9	34.1	39.0	195.4	193.6	156.6
1 p. m.	301.2	335.0	290.6	158.2	182.8	192.4	100.4	111.7	96.9	52.9	60.9	64.1	65.5	64.6	60.1	34.5	35.4	39.9	190.3	183.2	151.0
3 p. m.	292.9	346.6	287.4	154.7	187.8	200.4	97.6	115.5	95.8	51.2	62.6	66.8	65.4	64.8	58.9	34.6	35.2	41.1	189.3	184.5	143.4
5 p. m.	296.6	352.8	296.8	158.0	187.0	194.4	98.9	117.6	98.9	52.7	62.3	64.8	65.2	65.3	60.4	34.8	34.7	39.6	187.7	188.6	152.6
7 p. m.	318.2	358.8	294.6	150.8	187.0	197.2	106.1	119.6	98.2	50.3	62.3	65.7	67.8	65.7	59.9	32.2	34.3	40.1	211.0	191.8	151.9
9 p. m.	319.2	369.2	306.0	151.0	184.4	195.6	106.4	123.1	102.0	50.3	61.5	65.2	67.6	66.6	61.0	32.4	33.4	39.0	211.3	200.2	156.4

TABLE III.—*Variation of the water and dry matter in the leaves of Pride of Saline corn, Blackhull kafir, and Dwarf milo at Garden City, Kans.*—Contd.

JULY 17 AND 18, 1915

Period ending—	Water in 30 samples.			Dry matter in 30 samples.			Water per square meter of leaf.			Dry matter per square meter of leaf.			Percentage of water, wet basis.			Percentage of dry matter.			Percentage of water, dry basis.		
	Corn.	Kafir.	Milo.	Corn.	Kafir.	Milo.	Corn.	Kafir.	Milo.	Corn.	Kafir.	Milo.	Corn.	Kafir.	Milo.	Corn.	Kafir.	Milo.	Corn.	Kafir.	Milo.
July 17:	*Mgm.*	*Mgm.*	*Mgm.*	*Mgm.*	*Mgm.*	*Mgm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*									
6 a. m.	414.0	353.0	320.4	128.8	123.8	131.4	180.9	158.9	150.6	42.9	41.3	43.8	76.3	74.0	70.9	23.7	26.0	29.1	321.4	285.1	243.8
8 a. m.	391.8	352.6	312.0	137.2	132.8	133.0	176.3	161.8	148.6	45.7	44.3	44.3	74.1	72.6	70.0	25.9	27.4	30.0	285.6	265.5	234.6
10 a. m.	372.0	343.4	308.6	142.4	134.8	139.8	171.5	159.4	149.5	47.5	44.9	46.6	72.3	71.8	68.8	27.7	28.2	31.2	261.2	254.9	220.7
12 noon	355.8	327.4	294.8	143.0	145.8	148.2	166.3	157.7	147.7	47.7	48.6	49.4	71.3	69.2	66.5	28.7	30.8	33.5	248.8	224.6	198.9
2 p. m.	347.6	329.8	288.0	144.4	155.2	160.0	164.0	161.7	149.3	48.1	51.7	53.3	70.6	68.0	64.3	29.4	32.0	35.3	240.7	212.5	179.8
4 p. m.	351.0	339.6	306.0	143.4	154.8	148.8	164.8	164.8	151.6	47.8	51.6	49.6	71.0	68.7	67.3	29.0	31.7	32.7	244.8	219.4	205.6
6 p. m.	384.4	359.8	304.8	151.8	152.0	166.0	178.7	170.6	156.9	50.6	50.7	55.3	71.7	70.3	64.7	28.3	29.7	35.3	253.2	236.7	183.6
8 p. m.	403.2	372.8	319.6	149.4	149.8	155.4	184.2	174.2	161.7	49.8	49.9	51.8	72.9	71.3	66.0	27.1	28.7	34.0	269.9	248.9	205.7
10 p. m.	400.0	382.8	330.6	134.0	145.0	152.0	178.0	175.9	160.9	44.7	48.3	50.7	74.9	72.5	68.5	25.1	27.5	31.5	298.5	264.0	217.5
July 18:																					
12 midnight	391.7	373.6	333.8	130.6	145.0	150.2	174.1	172.9	161.3	43.5	48.3	50.1	75.0	72.0	69.0	25.0	28.0	31.0	300.0	257.7	222.2
2 a. m.	411.7	390.2	350.0	132.6	141.2	148.2	181.4	177.1	166.1	44.2	47.1	49.4	75.6	73.4	70.3	24.4	26.6	29.7	310.5	276.3	236.2
4 a. m.	417.0	438.6	363.0	133.2	138.0	145.6	183.4	192.2	169.5	44.4	46.0	48.5	75.8	76.1	71.4	24.2	23.9	28.6	313.1	317.8	249.3
6 a. m.	423.0	442.6	368.6	134.4	137.4	145.6	185.8	193.3	171.4	44.8	45.8.	48.5	75.9	76.3	71.6	24.1	23.7	28.4	314.7	322.1	252.7

JULY 31 AND AUGUST 1, 1915

July 31:																					
7 a. m.	368.4	357.8	313.6	140.2	153.0	140.4	122.8	119.3	104.5	46.7	51.0	46.8	72.4	70.0	69.1	27.6	30.0	30.9	262.8	233.9	223.2
9 a. m.	354.0	350.2	307.8	148.2	153.7	143.6	118.0	116.7	102.6	49.4	51.2	47.9	70.5	69.5	68.2	29.5	30.5	31.8	238.9	227.8	214.3
11 a. m.	339.3	342.4	301.6	142.1	160.6	155.0	113.1	114.1	100.5	47.4	53.5	51.7	70.5	68.7	66.1	29.5	31.3	33.9	238.8	213.2	194.6
1 p. m.	333.4	343.0	289.4	147.4	156.0	154.8	111.1	114.3	96.5	49.1	52.0	51.6	69.3	68.7	65.2	30.7	31.3	34.8	226.2	219.8	187.0
3 p. m.	348.2	358.0	295.8	142.6	156.0	161.8	116.1	119.3	91.9	47.5	52.0	53.6	70.9	69.6	64.6	29.1	30.4	35.4	244.2	229.6	182.8
5 p. m.	372.0	367.4	295.0	137.0	157.2	163.0	124.0	122.5	91.7	45.7	52.4	54.3	73.1	70.0	64.4	26.9	30.0	35.6	271.5	233.7	181.0
7 p. m.	370.8	371.8	307.8	142.0	155.4	160.2	123.6	123.9	102.6	47.3	51.8	53.4	72.3	70.5	65.8	27.7	29.5	34.2	261.1	239.3	192.1
9 p. m.	384.8	402.2	334.6	144.0	156.4	162.0	128.3	134.1	111.5	48.0	52.1	54.0	72.7	72.0	67.4	27.3	28.0	32.6	267.2	257.2	206.5
11 p. m.	388.8	402.2	338.4	139.6	149.9	155.0	129.6	134.1	112.8	46.5	49.3	51.7	73.6	72.8	68.6	26.4	27.2	31.4	278.5	268.3	218.3
August 1:																					
1 a. m.	394.8	411.4	343.4	138.4	149.4	154.6	131.6	137.1	114.5	46.1	49.1	51.5	74.0	73.4	69.0	26.0	26.6	31.0	285.3	275.4	222.1
3 a. m.	387.8	427.1	344.8	132.3	149.6	149.0	129.3	142.4	114.9	44.1	49.2	49.0	74.6	74.1	69.8	25.4	25.9	30.2	293.1	285.5	231.4
5 a. m.	370.8	404.4	343.6	128.0	142.6	144.4	123.6	134.8	114.5	42.7	47.5	48.1	74.3	73.9	70.4	25.7	26.1	29.6	289.7	283.6	238.0
7 a. m.	371.8	390.2	336.8	129.2	143.8	144.2	123.9	130.1	112.3	43.1	47.9	48.1	74.2	73.1	70.0	25.8	26.9	30.0	287.8	271.3	233.6
9 a. m.	354.8	382.2	311.8	128.4	147.8	147.4	118.3	127.4	103.9	42.8	49.3	49.1	73.4	72.0	66.5	26.6	28.0	33.5	276.3	258.6	211.5
11 a. m.	331.0	373.0	310.6	134.8	146.4	153.4	110.3	124.3	103.5	44.9	48.8	51.1	71.1	71.8	66.9	28.9	28.2	33.1	245.5	254.8	202.5
1 p. m.	332.6	367.8	308.2	130.0	151.0	159.0	110.9	122.6	102.7	43.3	50.3	53.0	71.9	70.9	66.0	28.1	29.1	34.0	255.8	243.6	193.8
3 p. m.	317.8	373.5	299.2	133.8	154.8	169.8	106.6	124.5	93.1	44.6	51.6	56.6	70.4	70.7	63.8	29.6	29.3	36.2	237.5	241.3	176.2
5 p. m.	345.2	385.4	314.0	138.2	154.6	165.2	115.1	128.5	104.7	46.1	51.5	55.1	71.4	71.4	65.5	28.6	28.6	34.5	249.8	249.3	190.0
7 p. m.	356.6	391.0	325.8	134.4	150.8	163.2	118.9	130.3	108.6	44.8	50.3	54.4	72.6	72.2	66.2	27.4	27.8	33.8	265.3	259.3	199.6

JULY 20–21, 1916

July 20:																					
7 a. m.	371.0	.....	333.8	132.0	.....	139.2	123.7	.....	111.3	44.0	.....	46.6	73.7	.....	70.4	26.3	.....	29.6	281.1	.....	239.8
9 a. m.	362.2	.....	321.0	136.0	.....	141.6	120.7	.....	107.0	45.3	.....	47.2	72.7	.....	69.4	25.3	.....	30.6	267.5	.....	226.7
11 a. m.	358.6	.....	319.4	140.2	.....	145.6	119.5	.....	106.5	46.7	.....	48.5	71.9	.....	68.7	28.1	.....	31.3	256.1	.....	219.3
1 p. m.	353.0	.....	313.6	142.0	.....	149.8	117.7	.....	104.5	47.3	.....	49.9	71.3	.....	67.7	28.7	.....	32.3	248.5	.....	209.5
3 p. m.	352.0	.....	320.0	146.4	.....	157.6	117.3	.....	106.7	48.8	.....	52.5	70.9	.....	67.0	29.1	.....	33.0	240.4	.....	203.1
5 p. m.	358.4	.....	321.6	145.6	.....	162.6	119.5	.....	107.2	48.5	.....	54.2	71.1	.....	66.4	28.9	.....	33.6	246.2	.....	197.7
7 p. m.	365.4	.....	326.0	142.6	.....	158.4	121.8	.....	108.7	47.5	.....	52.8	71.9	.....	67.3	28.1	.....	32.7	255.9	.....	205.9
9 p. m.	381.9	.....	340.1	139.1	.....	156.0	127.3	.....	113.4	46.4	.....	52.0	73.3	.....	68.6	26.7	.....	31.4	274.3	.....	218.1
11 p. m.	380.0	.....	348.5	134.8	.....	150.8	126.7	.....	116.2	45.0	.....	50.3	75.3	.....	69.8	24.7	.....	30.2	282.1	.....	231.1
July 21:																					
1 a. m.	379.6	.....	348.2	128.9	.....	147.2	126.5	.....	116.1	43.0	.....	49.7	74.7	.....	70.3	25.3	.....	29.7	294.5	.....	236.3
3 a. m.	386.6	.....	362.6	123.6	.....	143.8	128.9	.....	120.9	41.2	.....	47.9	75.8	.....	71.9	24.2	.....	28.1	312.6	.....	252.2
5 a. m.	386.2	.....	358.6	125.0	.....	140.2	128.7	.....	119.5	41.7	.....	46.7	75.5	.....	71.9	24.5	.....	28.1	309.2	.....	255.6
7 a. m.	371.4	.....	349.8	132.6	.....	144.2	123.5	.....	116.5	44.2	.....	48.1	73.7	.....	70.8	26.3	.....	29.2	280.3	.....	242.3
9 a. m.	362.8	.....	339.6	132.6	.....	148.2	120.9	.....	113.2	44.2	.....	49.4	73.2	.....	69.6	26.8	.....	30.4	273.5	.....	229.1
11 a. m.	345.0	.....	329.4	133.6	.....	149.4	115.0	.....	109.8	44.5	.....	49.8	72.1	.....	68.8	27.9	.....	31.2	258.2	.....	220.5
1 p. m.	334.4	.....	318.8	135.0	.....	153.4	111.5	.....	106.3	45.0	.....	51.1	69.8	.....	67.5	30.2	.....	32.5	247.8	.....	207.9
3 p. m.	345.6	.....	327.8	131.6	.....	158.3	115.2	.....	109.3	43.7	.....	52.8	72.4	.....	67.4	27.6	.....	32.6	262.8	.....	207.8
5 p. m.	356.2	.....	334.4	139.0	.....	160.8	118.7	.....	111.5	46.3	.....	53.6	71.9	.....	67.5	28.1	.....	32.5	256.5	.....	207.9
7 p. m.	379.7	.....	351.8	135.8	.....	160.4	126.6	.....	117.3	45.3	.....	53.5	70.5	.....	68.7	29.5	.....	31.3	279.2	.....	219.1

JULY 26 AND 27, 1916

July 26:																					
7 a. m.	355.5	338.4	303.1	139.8	141.0	153.0	118.8	112.8	101.0	46.6	47.0	51.0	71.7	70.5	66.4	28.3	29.5	33.6	254.2	239.5	198.2
9 a. m.	342.8	333.8	302.8	143.8	146.2	157.2	114.3	111.3	100.9	47.9	48.7	52.4	70.4	69.5	65.8	29.6	30.5	34.2	238.3	228.4	192.5
11 a. m.	325.6	327.0	299.0	147.8	151.4	167.0	108.5	109.0	99.7	49.3	50.5	55.7	68.7	68.3	64.1	31.3	31.7	35.9	220.3	216.2	179.2
1 p. m.	322.6	326.6	294.0	146.2	153.2	170.4	107.5	108.9	98.0	48.7	51.1	56.8	68.8	68.0	63.3	31.2	32.0	36.7	220.5	213.1	172.5
3 p. m.	326.0	332.2	296.0	147.4	156.2	179.4	108.7	110.7	98.7	49.1	52.1	59.8	68.8	66.8	62.2	31.2	33.2	37.8	221.2	212.6	165.2
5 p. m.	336.0	338.2	303.4	147.0	161.2	181.6	112.0	112.7	101.1	49.0	53.7	60.5	69.5	67.7	62.5	30.5	32.3	37.5	228.5	209.8	167.2
7 p. m.	354.0	352.3	315.8	149.0	160.0	176.2	118.0	117.4	105.3	49.7	53.3	58.7	70.3	68.7	64.2	29.7	31.3	35.8	237.6	220.2	179.3
9 p. m.	361.0	366.0	323.6	146.0	154.7	169.1	120.3	122.0	107.9	48.7	51.2	56.4	71.2	70.2	65.6	28.8	29.8	34.4	247.2	236.5	191.2
11 p. m.	370.6	375.8	330.5	138.6	147.5	161.1	123.5	125.3	110.2	46.2	49.2	53.7	72.7	71.8	67.2	27.3	28.2	32.8	267.2	254.5	205.2
July 27:																					
1 a. m.	379.4	383.2	338.0	136.8	145.8	164.6	126.5	127.7	112.7	45.6	48.6	54.9	73.4	72.4	67.2	26.6	27.6	32.8	277.5	262.8	205.8
3 a. m.	379.6	389.0	340.4	136.0	144.9	162.0	126.5	129.7	113.5	45.3	48.3	54.0	73.6	72.8	67.5	26.4	27.6	32.5	278.8	268.5	210.3
5 a. m.	375.8	391.4	350.6	134.4	136.2	155.6	125.3	130.5	116.9	44.8	45.4	51.9	73.6	74.1	69.2	26.4	25.9	30.8	279.6	287.2	225.3
7 a. m.	367.9	383.6	348.8	136.1	140.8	159.6	122.6	127.9	116.3	45.4	46.9	53.2	72.9	73.1	68.6	27.1	26.9	31.4	270.2	272.4	218.2
9 a. m.	351.4	372.9	329.3	138.4	143.7	165.7	117.1	124.3	109.8	46.1	47.9	55.2	71.7	72.1	66.5	28.3	27.9	33.5	254.0	259.4	198.8
11 a. m.	341.6	356.4	322.0	136.0	151.5	168.0	113.5	118.8	107.3	45.3	50.5	56.0	71.5	70.1	65.5	28.5	29.9	34.5	251.2	235.3	191.8
1 p. m.	322.8	353.0	315.2	142.8	147.1	175.5	107.6	117.7	105.1	47.6	49.0	58.5	69.3	70.5	64.2	30.7	29.5	35.8	226.2	240.2	179.8
3 p. m.	336.8	365.6	324.7	134.4	151.5	176.2	112.3	121.9	108.2	44.8	50.5	58.7	71.4	70.7	64.8	28.6	29.3	35.2	250.5	241.3	184.2
5 p. m.	365.0	381.8	331.3	132.9	147.6	183.1	121.7	127.3	110.4	44.3	49.2	61.0	73.3	72.1	64.4	26.7	27.9	35.6	274.8	258.4	181.0
7 p. m.	367.7	392.8	340.3	136.1	149.6	175.9	122.6	130.9	113.4	45.4	49.9	58.6	72.9	72.4	65.9	27.1	27.6	34.1	270.2	262.2	193.7

TABLE III.—*Variation of the water and dry matter in the leaves of Pride of Saline corn, Blackhull kafir, and Dwarf milo at Garden City, Kans.*—Contd.

AUGUST 1 AND 2, 1916.

Period ending—	Water in 30 samples.			Dry matter in 30 samples.			Water per square meter of leaf.			Dry matter per square meter of leaf.			Percentage of water, wet basis.			Percentage of dry matter.			Percentage of water, dry basis.		
	Corn.	Kafir.	Milo.	Corn.	Kafir.	Milo.	Corn.	Kafir.	Milo.	Corn.	Kafir.	Milo.	Corn.	Kafir.	Milo.	Corn.	Kafir.	Milo.	Corn.	Kafir.	Milo.
	Mgm.	*Mgm.*	*Mgm.*	*Mgm.*	*Mgm.*	*Mgm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*	*Gm.*									
August 1:																					
7 a. m.	369.9	.....	314.2	147.3	.....	152.4	123.3	.....	104.7	49.1	.....	50.8	71.5	.....	67.5	28.5	.....	32.5	250.8	.....	206.2
9 a. m.	355.7	.....	305.9	149.9	.....	160.2	118.6	.....	102.0	50.0	.....	53.4	70.3	.....	65.6	29.7	.....	34.4	238.2	.....	190.7
11 a. m.	337.3	.....	299.6	154.3	.....	167.0	112.4	.....	99.9	51.4	.....	55.7	68.6	.....	64.2	31.4	.....	35.8	218.8	.....	179.2
1 p. m.	320.6	.....	293.6	153.8	.....	175.0	106.9	.....	97.9	51.3	.....	58.3	67.5	.....	62.6	32.5	.....	37.4	208.4	.....	167.5
3 p. m.	312.7	.....	297.0	154.2	.....	183.1	104.2	.....	99.0	51.4	.....	61.0	66.9	.....	61.7	33.1	.....	38.3	202.8	.....	162.1
5 p. m.	345.1	.....	306.0	155.0	.....	184.5	115.0	.....	102.0	51.7	.....	61.5	69.0	.....	62.4	31.0	.....	37.6	222.9	.....	165.9
7 p. m.	368.0	.....	319.7	153.0	.....	180.7	122.7	.....	106.6	51.0	.....	60.2	70.6	.....	62.9	29.4	.....	37.1	240.5	.....	176.7
9 p. m.	371.0	.....	326.0	150.5	.....	174.1	123.7	.....	108.7	50.2	.....	58.0	71.1	.....	65.1	28.9	.....	34.9	246.6	.....	187.2
11 p. m.	385.8	.....	338.0	147.4	.....	173.4	128.6	.....	112.7	49.1	.....	57.8	72.3	.....	66.1	27.7	.....	33.9	261.7	.....	195.0
August 2:																					
1 a. m.	393.8	.....	349.7	143.0	.....	166.8	131.3	.....	116.6	47.7	.....	55.6	73.3	.....	67.7	26.7	.....	32.3	275.2	.....	209.5
3 a. m.	387.7	.....	346.8	141.9	.....	164.8	129.2	.....	115.6	47.3	.....	54.9	73.2	.....	67.8	26.8	.....	32.2	273.3	.....	210.3
5 a. m.	374.6	.....	345.0	139.8	.....	156.4	124.9	.....	115.0	46.6	.....	52.1	72.8	.....	68.8	27.2	.....	31.2	267.9	.....	220.8
7 a. m.	381.7	.....	352.3	141.4	.....	162.6	127.2	.....	117.4	47.1	.....	54.2	72.9	.....	68.4	27.1	.....	31.6	269.5	.....	216.8
9 a. m.	358.4	.....	337.2	139.4	.....	164.8	119.5	.....	112.4	46.5	.....	54.9	72.0	.....	67.2	28.0	.....	32.8	258.3	.....	204.9
11 a. m.	346.4	.....	329.4	151.0	.....	180.0	115.5	.....	109.8	50.3	.....	60.0	69.7	.....	64.7	30.3	.....	35.3	229.5	.....	183.0
1 p. m.	346.2	.....	329.9	154.4	.....	187.2	115.4	.....	110.0	51.5	.....	62.4	69.2	.....	63.8	30.8	.....	36.2	224.3	.....	176.1
3 p. m.	323.4	.....	320.0	140.8	.....	185.0	107.8	.....	106.7	46.9	.....	61.7	69.7	.....	63.4	30.3	.....	36.6	229.8	.....	172.8
5 p. m.	345.6	.....	338.8	149.0	.....	188.0	115.2	.....	112.9	49.7	.....	62.7	69.9	.....	64.3	30.1	.....	35.7	231.9	.....	180.1
7 p. m.	.....	.....	340.6	.....	.....	185.0	.....	.....	113.5	.....	.....	61.7	.....	.....	64.8	.....	.....	35.2	.....	.....	184.0

AUGUST 10 AND 11, 1916.

August 10:																					
7 a. m.	348.3	371.4	303.5	166.2	163.2	181.2	116.1	123.8	101.2	55.4	54.4	60.4	67.7	69.4	62.6	32.3	30.6	37.4	209.5	227.5	167.5
9 a. m.	343.4	368.0	307.1	167.6	165.8	186.8	114.5	122.7	102.4	55.9	55.3	62.3	67.2	69.0	62.4	32.8	31.0	37.6	204.8	221.9	164.3
11 a. m.	332.1	348.0	298.0	166.8	168.0	196.0	110.7	116.0	99.3	55.6	56.0	65.3	66.6	67.4	60.3	33.4	32.6	39.7	199.0	207.2	152.0
1 p. m.	316.8	339.4	295.8	165.8	164.0	195.2	105.6	113.1	98.6	55.3	54.7	65.1	65.6	67.4	60.3	34.4	32.6	39.7	191.0	206.9	151.5
3 p. m.	315.4	338.3	294.5	167.8	170.2	201.4	105.1	112.8	98.2	55.9	56.7	67.1	65.3	66.5	59.4	34.7	33.5	40.6	188.0	198.7	146.3
5 p. m.	322.9	349.2	298.3	172.4	169.2	203.2	107.6	116.4	99.4	57.5	56.4	67.7	65.2	67.4	59.5	34.8	32.6	40.5	187.3	206.4	146.7
7 p. m.	343.0	379.9	312.3	168.4	170.2	196.0	114.3	126.6	104.1	56.1	56.7	65.3	67.1	69.1	61.4	32.9	30.9	38.6	203.7	223.2	159.4
9 p. m.	359.1	389.5	314.3	166.2	168.0	190.7	119.7	129.8	104.8	55.4	56.0	63.6	68.4	69.9	62.2	31.6	30.1	37.8	216.2	231.7	164.7
11 p. m.	364.1	393.9	334.1	162.6	165.4	194.0	121.4	131.3	111.4	54.2	55.1	64.7	69.1	70.5	63.3	30.9	29.5	36.7	224.0	238.1	167.1

August 11:																				
1 a. m.	357.5	392.0	330.2	157.6	164.3	189.1	119.2	130.7	110.1	53.5	54.8	63.0	69.4	70.5	63.6	30.6	29.5	36.4	226.7	238.5	174.6
3 a. m.	358.6	393.5	331.6	159.4	160.0	185.0	119.5	131.2	110.5	53.1	53.3	61.7	69.2	71.1	64.2	30.8	28.9	35.8	225.0	246.0	179.3
5 a. m.	301.4	395.4	332.6	155.5	157.9	182.6	120.5	131.8	110.9	51.8	52.6	60.9	69.9	71.5	64.8	30.1	28.5	35.2	232.4	250.4	182.2
7 a. m.	354.8	395.5	334.8	159.0	160.9	187.5	118.3	131.8	111.6	53.0	53.6	62.5	69.1	70.9	64.1	30.9	29.1	35.9	223.0	245.7	178.5
9 a. m.	347.0	381.0	324.6	160.5	164.5	195.0	115.7	127.0	108.2	53.5	54.8	63.0	68.4	69.8	62.5	31.6	30.2	37.5	216.2	231.5	166.4
11 a. m.	343.4	374.4	319.2	163.1	169.3	200.8	114.5	124.5	106.4	54.4	56.4	66.9	67.8	68.9	61.4	32.2	31.1	38.6	210.5	221.3	158.9
1 p. m.	326.4	356.1	316.1	162.6	168.0	208.3	108.8	118.7	105.4	54.2	56.0	69.4	66.7	67.9	60.3	33.3	32.1	39.7	200.6	212.0	151.7
3 p. m.	319.2	353.7	309.3	169.6	169.8	213.3	106.4	117.9	103.1	56.5	56.6	71.1	65.3	67.7	59.2	34.7	32.3	40.8	188.2	208.3	145.0
5 p. m.	340.2	383.4	329.0	165.6	164.2	209.1	113.4	127.8	109.7	55.2	54.7	69.7	67.3	70.1	61.2	32.7	29.9	38.8	200.5	233.5	157.4
7 p. m.	351.3	394.2	341.6	162.9	165.1	209.0	117.1	131.4	113.9	54.3	55.0	69.7	68.3	70.5	62.0	31.7	29.5	38.0	215.7	238.8	163.4

TABLE IV.—*Summary of the variation of the water content of the leaves of corn, kafir, and milo during the years 1914, 1915, and 1916, at Garden City, Kans.*

Time.	Plant.	Loss.			Gain.			Net gain or loss.	
		Number of cases of loss.	Average loss of leaf water per square meter of leaf.	Average percentage of loss based on leaf water at beginning of period.	Number of cases of gain.	Average gain of leaf water per square meter of leaf.	Average per centage of loss based on leaf water at beginning of period.	Per square meter of leaf.	Percentage based on leaf water at beginning of period.
			Gm.			*Gm.*		*Gm.*	
7 a. m to 9 a. m.	Corn	21	4.1	3.5	0	0	0	[a] 4.1	[a] 3.5
	Kafir	15	3.3	2.8	1	3.8	3.2	[a] 3.0	[a] 2.5
	Milo	18	4.2	4.0	3	1.3	1.3	[a] 3.6	[a] 3.4
9 a. m. to 11 a. m.	Corn	18	4.8	4.2	2	2.5	2.2	[a] 4.1	[a] 3.8
	Kafir	16	3.9	3.4	1	1.3	1.0	[a] 3.7	[a] 3.4
	Milo	20	2.2	2.1	1	5.2	5.6	[a] 1.9	[a] 1.8
11 a. m. to 1 p. m.	Corn	15	3.7	3.4	6	2.9	2.4	[a] 2.5	[a] 2.2
	Kafir	14	3.1	2.8	3	4.2	3.6	[a] 2.5	[a] 2.2
	Milo	13	1.9	1.9	7	1.7	1.6	[a] 1.1	[a] 1.1
1 p. m. to 3 p. m.	Corn	10	3.1	2.8	10	2.5	2.2	[a] 1.8	[a] 1.6
	Kafir	4	2.5	2.1	13	3.1	2.7	[b] 2.0	[b] 1.7
	Milo	11	3.3	3.3	10	2.6	2.5	[a] 1.7	[a] 1.6
3 p. m. to 5 p. m.	Corn	4	2.7	2.3	17	5.7	4.9	[b] 4.6	[b] 4.0
	Kafir	0	0	0	17	4.3	3.6	[b] 4.3	[b] 3.6
	Milo	4	4.1	4.2	17	3.9	3.7	[b] 3.2	[b] 3.0

[a] Loss. [b] Gain.

VARIATION OF THE WATER IN THE LEAVES

I. WATER PER SQUARE METER OF LEAF

The average water content per square meter of leaf for the day and night periods was 123.2 gm. for corn, 126.3 gm. for kafir, and 111.4 gm. for milo. The amount of water in the leaves of milo was found to be strikingly lower than that of either corn or kafir leaves at all times of the day and night. The amount of water in the leaves of kafir for all the periods averaged slightly higher than that of corn. In some experiments the corn leaves showed a greater amount of water than the kafir, while in other experiments the kafir leaves had the higher amount. The leaves of kafir that were used in one experiment in 1914, and in two experiments in 1916, were, however, a few weeks younger than the corn leaves and consequently had more water per unit of area, so that, on the whole, there appears to be little, if any, difference in the average water content of the leaves of corn and Blackhull kafir at the same stage of development.

The water content of the leaves of corn, kafir, and milo averaged 118.5, 120.0, and 107.0 gm. per square meter of leaf, respectively, for the day periods, and, taken in the same order, 127.9, and 132.7, and 115.5 gm. for the night periods. This made an average difference between the day

and night of 9.4, 12.7, and 8.5 gm. of water per square meter of leaf, respectively, for corn, kafir, and milo.

For the 22 days the minimum amount of water in the corn leaves was reached 4 times at 11 a. m.,[1] 7 times at 1 p. m., 10 times at 3 p. m., and once at 5 p. m., while in the same number of periods the milo leaves reached their minimum amount of water twice at 11 a. m., 10 times at 1 p. m., 9 times at 3 p. m., and once at 9 a. m. For 18 days the kafir leaves showed the minimum amount of water twice at 11 a. m., 13 times at 1 p. m., and 3 times at 3 p. m. The average difference between the maximum and minimum amounts of water in the leaves during the day was 13.8, 8.4, and 7.8 gm. per square meter of leaf surface, respectively, for corn, kafir, and milo. The maximum evaporation as measured by the Livingston porous-cup atmometers occurred 18 times between 2 and 3 p. m. and four times between 3 and 5 p. m. The evaporation as represented in figures 1 to 10 is plotted for 2-hour periods, so that the hour of maximum evaporation may not be shown by the curves. The minimum amount of water in the leaves during the day occurred 7 times for corn, twice for kafir, and 7 times for milo at the same time as the maximum evaporation. In 9 cases for corn, 12 for kafir, and 10 for milo the minimum amount of water in the leaves was reached two hours before maximum evaporation, while in 5 cases for corn, 4 for kafir, and 4 for milo the lowest water content of the leaves occurred four hours before the maximum evaporation. Thus, in two-thirds of the cases of corn and milo and in nine-tenths of the cases of kafir, the minimum amount of water in the leaves occurred under the condition of these experiments from two to four hours earlier than did the maximum evaporation, as shown by the Livingston porous-cup atmometer.

During the night the maximum water content of the corn leaves was reached 3 times at 11 p. m., 3 times at 1 a. m., twice at 3 a. m., once at 9 p. m., and twice at 5 a. m. The leaves of kafir showed the greatest amount of water once at 11 p. m., 5 times at 1 a. m., and 3 times at 5 a. m., while the milo leaves reached their maximum water content once at 11 p. m., 4 times at 1 a. m., 3 times at 3 a. m., twice at 5 a. m., and once at 7 a. m. The lowest evaporation for the 11 night periods occurred 9 times between 4 and 5 a. m. and twice between 2 and 3 a. m. The average difference between the minimum and maximum water content of the leaves per square meter of surface during the night was 10.3 gm. for corn, 16 gm. for kafir, and 13.1 gm. for milo. The difference between the average minimum water content of the leaves during the day and the average maximum water content during the night was 23.8, 25.9, and 21.7 gm. per square meter of leaf for corn, kafir, and milo, respectively. It is worthy of note that in all the night experiments abundant guttation

[1] In the following discussion the maximum or minimum amount of water or dry matter in the leaves is considered as occurring at the close of a 2-hour period, but, as a matter of fact, it might have occurred at any time during the two preceding hours.

was observed on the leaves of both milo and kafir, while in only two observations was it noticeable on the leaves of corn, and then it appeared in only very small amounts.

II. PERCENTAGE OF WATER

The average percentage of water for both the days and nights was 70.7 for corn, 69.9 for kafir, and 65.5 for milo. The average percentage of water in the leaves during the 22 days was found to be 71.3, 70.3, and 65.8 for corn, kafir, and milo, respectively. Taken in the same order, the average percentage of water during the 10 night periods was 70.2 69.6, and 65.3, a difference between the night and day of 1.1, 0.7, and 0.5 per cent, respectively, for the corn, kafir, and milo. The minimum percentage of water in the leaves during the day occurred from 11 a. m. to 5 p. m. In most cases the minimum percentage was reached between 1 and 3 p. m. In almost one-third of the cases the percentage of water varied little, if any, from 11 a. m. to 3 p. m. The minimum percentage of water in the leaves occurred at 3 p. m. more frequently than at any other period. The average difference between the maximum and minimum percentage of water in the leaves during the day was 3.5 for corn, 3.2 for kafir, and 4.5 for milo.

The maximum percentage of water in the leaves of the corn during 10 nights occurred 5 times at 5 a. m., 3 times at 3 a. m., and twice at 1 a. m. For the same number of periods the milo leaves reached their maximum percentage of water 7 times at 5 a. m., once at 3 a. m., and twice at 1 a. m. In 8 night periods the kafir leaves showed the greatest percentage of water 5 times at 5 a. m., once at 3 a. m., and twice at 1 a. m. The average difference between the minimum and maximum percentage of water in the leaves during the night was, respectively, 3.0, 4.2, and 4.7 for corn, kafir, and milo.

The average difference between the maximum percentage of water in the leaves at night and the minimum percentage of water during the day was found to be 5.4 for corn, 5.9 for kafir, and 6.0 for milo.

III. PERCENTAGE OF WATER (DRY BASIS)

For all the day and night periods the average percentage of water in the leaves on a dry basis; or, in other words, the ratio of the weight of water to the weight of dry matter was 251.2 for corn, 234.5 for kafir, and 195.1 for milo. The average percentage of water on this basis for all the day periods was 240.0, 218.2, and 183.1, respectively, for corn, kafir, and milo, while, in the same order, the average percentage during the 10 nights was 256.8, 235.9, and 197.0. This made an average difference between the maximum and minimum percentage of water in the leaves during the night and day of 16.8 for corn, 17.7 for kafir, and 13.9 for milo. The average variation of the percentage of water on a dry basis during the daylight hours was 39.5 for corn, 31.1 for kafir,

and 35.9 for milo. The minimum percentage of water on this basis occurred for the three plants for the most part from 1 to 5 p. m. The maximum percentage of water in the leaves of corn occurred, during 11 nights, 7 times at 5 a. m., twice at 3 a. m., and twice at 1 a. m. The maximum percentage of water in the leaves of milo with but one exception was found to be at 5 a. m. In 9 nightly observations of kafir leaves the maximum percentage of water occurred 6 times at 5 a. m., once at 3 a. m., and twice at 1 a. m. The average difference between the minimum and maximum percentage of leaf water during the night was 37.5 for corn, 47.5 for kafir, and 40.0 for milo. The average range between the maximum percentage of water in the leaves during the night and the minimum percentage during the day was 67.8, 67.2, and 51.2 for corn, kafir, and milo, respectively.

VARIATION OF THE DRY MATTER

1. DRY MATTER PER SQUARE METER OF LEAF

The dry weight of a given area of milo leaf was always found to be greater than an equal area of either corn or kafir leaves of the same age. The average dry weight of a square meter of leaf for all the observations made during these experiments was found to be 48.2 gm. for corn, 52.5 gm. for kafir, and 56.2 gm. for milo. The average amounts of dry matter per square meter of leaf during 17 days was 49.1, 54.1, and 57.4 gm., respectively, for corn, kafir, and milo, while, taken in the same order, the average dry weight of the same area of leaves was 48.4, 53.4, and 56.9 gm. This makes an average difference in dry weight of a square meter of leaf between the day and night of 0.7 gm. for corn and kafir and 0.5 gm. for milo. These differences are much less than one would expect; but a glance at the dry-matter curves shows that in most cases there was a gradual increase in dry matter from 5 a. m. till 3 to 5 p. m., and that there was little depletion of dry matter before 7 p. m. After that there was in most cases a gradual depletion of dry matter in the leaves until 5 a. m. Since there was a gradual increase of dry matter during the day and a corresponding decrease during the night, the average leaf weight for the day and the night was practically the same.

The maximum amount of dry matter in the leaves of corn for 21 days occurred 4 times at 1 p. m., 5 times at 3 p. m., 11 times at 5 p. m., and once at 7 p. m. The dry matter of the leaves of milo for the same number of periods reached a maximum 6 times at 3 p. m., 14 times at 5 p. m., and once at 7 p. m. In 17 day periods the leaves of kafir reached their maximum amount of dry matter 7 times at 3 p. m., 9 times at 5 p. m., and once at 7 p. m. On August 16, 1916, the dry matter in the leaves of all three plants never increased over what it was at 7 a. m. It is seen from the figures quoted above that the maximum amount of dry matter

in the leaves of the three plants occurs in the most cases between 2 and 5 p. m. The average difference between the minimum and maximum amount of dry matter in the leaves during the day was 4.0, 4.8, and 8.0 gm. for corn, kafir, and milo, respectively.

The minimum amount of dry matter in the leaves of corn during 10 nights from 7 p. m. to 7 a. m. occurred 8 times at 5 a. m., once at midnight, and once at 3 a. m., while the leaves of milo in the same number of experiments reached their minimum dry-matter content 7 times at 5 a. m., twice at 7 a. m., and once at 7 p. m. During the 8 nights that the leaves of kafir were examined, the minimum amount of dry matter occurred at 5 a. m. in all cases. Sunrise occurred about 5 a. m. at the time of these experiments.

The average difference between the maximum and minimum amount of dry matter per square meter of leaf during the night periods was 5.3, 5.2 and 6.3 gm., respectively, for the corn, kafir, and milo.

The maximum amount of dry matter in the leaves of corn during the night occurred 7 times at 7 p. m., twice at 9 p. m., and once at 11 p. m. The leaves of milo during the same number of periods reached the maximum amount of dry matter 7 times at 7 p. m., twice at 11 p. m., and once at 9 p. m. In 8 night experiments with kafir the dry matter in the leaves was the highest 5 times at 7 p. m., twice at 9 p. m., and once at 11 p. m. The average variation of dry matter from the minimum amount in the leaves at night to the maximum amount in the leaves during the day was 6.2, 6.0, and 7.7 gm. per square meter of leaf for corn, kafir, and milo, respectively.

Several cases were noted where a marked increase in the dry matter of the leaves occurred for one or more 2-hour periods during the night. On August 10, 1914, the dry matter decreased in the leaves of all three of the plants from 5 to 9 p. m. During the next 2-hour period the dry matter in the leaves of corn increased from 46.9 to 48.6 gm. per square meter of leaf, while in the same time an equal area of kafir leaf increased in dry weight from 50.9 to 51.9 gm. From 9 p. m. to 11 p. m. the dry matter in the leaves of milo increased 1.6 gm. per square meter of leaf and showed no signs of depletion until 1 a. m. On August 15, 1914, the dry matter in the leaves increased 3.5, 1.7, and 2.8 gm. per square meter of leaf, respectively, for corn, kafir, and milo between 7 and 9 p. m. On August 25, 1914, the dry matter in the leaves of corn dropped from 54.3 gm. per square meter at 5 p. m. to 51.9 gm. at 7 p. m., and then increased the next two periods to 53.7 gm. at 11 p. m. The kafir leaves decreased in dry matter per square meter from 60.4 gm. at 5 p. m. to 58.7 gm. at 7 p. m., and then gradually increased during the next two periods to 61.3 gm. at 11 p. m. After 11 p. m. the dry matter in the leaves of both corn and kafir began to decrease. The dry matter in the milo leaves decreased 2.6 gm. per square meter of leaf surface from 5 to 7 p. m. During

the next two hours it increased 6.7 gm., then decreased 2.2 gm. until 11 p. m., when the amount of dry matter remained constant until 1 a. m., after which a gradual depletion began to occur. (See Table III, Aug. 10–26, 1914, and fig. 3, 4, and 5.)

II. PERCENTAGE OF DRY MATTER

The average percentage of dry matter in the leaves during both the day and night was found to be 28.7 for corn, 30.1 for kafir, and 34.3 for milo. The average percentage of dry matter in the leaves during the day periods was 29.0, 30.5, and 34.7, respectively, for corn, kafir, and milo, while taken in the same order the average percentage of dry matter during the 10 night periods was 28.3, 29.8, and 33.9. This made an average difference in the percentage of dry matter between the day and night of approximately 0.7 for all three plants. With but few exceptions the maximum percentage of dry matter in the leaves of all three plants occurred between 11 a. m. and 3 p. m. The average difference between the maximum and minimum percentage of dry matter during the day was 3.5 for corn, 3.3 for kafir, and 4.6 for milo. The minimum percentage of dry matter in the leaves of corn during the night occurred twice at 1 a. m., 3 times at 3 a. m., and 5 times at 5 a. m. In all the 10 night experiments with milo the minimum percentage of dry matter occurred at 5 a. m. In 8 night experiments with kafir the minimum percentage of dry matter was in 2 cases at 1 a. m. and in 6 cases at 5 a. m. The average difference between the maximum and minimum percentage of dry matter during the night was 3.0, 4.2, and 4.8 for corn, kafir, and milo, respectively. The average difference between the maximum percentage of dry matter during the day and the minimum percentage during the night was 5.1 for corn, 5.9 for kafir, and 6.0 for milo.

For the purpose of comparison, the results have been obtained by other investigators in their study of the daily variation of the water content of leaves are briefly reviewed here. Lloyd[1] found that the percentage of water on a dry basis in the leaves of *Fouquieria splendens* varied from 225 to 300 as extreme limits between day and night and that the diminution of water in the leaves began at daybreak and continued until some time between noon and 4 p. m. After that time the water in the leaves increased till approximately 4 a. m. In experiments with the cotton plant, Lloyd[2] found that the leaf water stated in percentage of dry weight varied under usual conditions between 318 and 220 per cent and that the minimum leaf water content was reached at 2 p. m. or thereabouts. The amount of loss of leaf water when thus determined was from 7 to 15 per cent of the initial amount at sunrise.

[1] LLOYD, F. E. THE RELATION OF TRANSPIRATION AND STOMATAL MOVEMENTS TO THE WATER CONTENT OF THE LEAVES IN FOUQUIERIA SPLENDENS. *In* Plant World, v. 15, no. 1, p. 1–14, 1 fig. 1912.

[2] ———. LEAF WATER AND STOMATAL MOVEMENT IN GOSSYPIUM AND A METHOD OF DIRECT VISUAL OBSERVATION OF STOMATA IN SITU. *In* Bul. Torrey Bot. Club, v. 40, no. 1, p. 1–26, 3 fig. 1913.

Livingston and Brown [1] investigated the water content of the leaves of numerous plants growing in the vicinity of Tucson, Ariz., and found that the time of the minimum water content of the leaves fell within an hour or two of the maximum evaporation rate. The minimum moisture content of the leaves of most of these plants, estimated on both a dry and a wet basis, occurred between 1 and 5 p. m.

GENERAL CONCLUSIONS

VARIATION OF THE WATER CONTENT

The leaves of milo contained less water at all times than the leaves of either corn or kafir at the same stage of development. The average water content per square meter of leaf for all the observations made was 111.4 gm. for milo, 123.2 gm. for corn, and 126.3 gm. for kafir. The amount of water in the leaves of corn and kafir was practically the same at like stages of growth. The small difference between the average amount of water in the leaves of kafir as compared with those of corn is due to the fact that in one experiment in 1914 and in two experiments in 1916 the leaves of the kafir were about 10 days younger than those of the corn and, as a consequence, contained a greater amount of water.

Under the conditions of these experiments, the leaves of corn in most cases were wilted during the greater portion of the day. The first signs of wilting were most generally observed between 9 a. m. and 10 a. m., and in most cases no visible wilting could be observed after 4 p. m. The kafir leaves wilted during the day, but not to the extent that the leaves of the corn did, while the milo leaves showed little or no signs of wilting. Under these conditions the average range between the maximum and minimum amount of water per square meter of leaf during the 2-hour periods from 7 a. m. to 7 p. m. was 13.8 gm. for corn, 8.4 gm. for kafir, and 7.8 gm. for milo.

Table IV shows the average gain or loss of leaf water during each 2-hour period of the day from 7 a. m. to 5 p. m. for the experiments conducted in 1914, 1915, and 1916. The average gain or loss for each period is expressed in grams per square meter of leaf and in percentage based on the water in the leaf at the beginning of the 2-hour period.

The time of the day when the loss of leaf water ceases and an increase in its amount begins depends upon the aerial conditions under which the experiment is conducted. Under the conditions of these experiments the leaves of the three plants, with but few exceptions, showed a decrease in the water content between 7 and 11 a. m. In one-third of the observations for corn and milo and in one-fifth of the observations for

[1] LIVINGSTON, B. E., and BROWN, W. H. RELATION OF THE DAILY MARCH OF TRANSPIRATION TO VARIATIONS IN THE WATER CONTENT OF FOLIAGE LEAVES. *In* Bot. Gaz., v. 53, no. 4, p. 309-330, pl. 24-25. 1912.

kafir the leaves showed a gain in their leaf water between 11 a. m. and 1 p. m. From 1 to 3 p. m. the leaves gained in the amount of their leaf water in one-half of the observations of corn and milo and in three-fourths of the observations of kafir, while from 3 to 5 p. m. the leaves of kafir showed a gain in water in all cases. In only four cases did the leaves of milo and corn show a loss of water during this period. In the following discussion the cases of the loss of leaf water only will be considered.

The average loss of leaf water per square meter of leaf, between 7 and 9 a. m. was 4.1 gm. for corn, 3.3 gm. for kafir, and 4.2 gm. for milo, while the percentage of loss based on the amount of water in the leaf at the beginning of the period was 3.5, 2.8, and 4.0, respectively, for corn kafir, and milo. During this period the water in the leaves of corn and milo decreased in like amount, but the percentage loss was higher for milo than for corn. The average loss of the leaf water of the kafir during this period was the least for the three plants, both in percentage and in actual amount.

From 9 to 11 a. m. the water content of the leaves per square meter of leaf decreased 4.8, 3.9, and 2.2 gm., respectively, for corn, kafir, and milo, from what it was at the close of the previous period, while the percentage of loss was 4.2 for corn, 3.4 for kafir, and 2.1 for milo. The rate of water loss during this period thus increased markedly for corn and kafir, both in percentage and in actual amount, while the loss for milo was only one-half of what it was from 7 to 9 a. m. From 11 a. m. to 1 p. m., the decrease in the amount of leaf water for each square meter of leaf was 3.7 gm. for corn, 3.1 gm. for kafir, and 1.9 gm. for milo, while, taken in the same order, the percentage loss was 3.4, 2.8, and 1.9. The rate of loss during this period decreased markedly for corn and kafir, while the change in the rate of milo was very slight. From 1 to 3 p. m. the average loss of leaf water was 3.1, 2.5, and 3.3 gm. for each square meter of leaf for corn, kafir, and milo, respectively, while the percentage loss was 2.8 for corn, 2.1 for kafir, and 3.3 for milo. While the rate of the loss of water in the leaves of corn and kafir continued to decrease, the loss in the leaves of milo showed a marked increase, both in percentage and actual amount, over what it was at the close of the previous period.

A consideration of the loss of the leaf water during the day shows that from 7 to 9 a. m. the rate of loss was practically the same for corn and milo and the least for kafir. From 9 to 11 a. m., as the aerial conditions became more severe, the rate of loss increased for corn and kafir, but decreased almost one-half for milo. During the next two hours the rate of loss decreased for all three plants, but the rate of loss was approximately twice as great for corn and kafir as for milo. From 1 to 3 p. m. the rate of loss continued to decrease, while the rate of loss of milo increased over 1 per cent. These results seem to indicate that the

absorption of water by the milo from the soil and its translocation to leaves was proceeding more rapidly in proportion to the loss of water from the plant than in the case of either corn or kafir. The fact that the leaves of milo seldom wilted during the day also indicated that fact. The wilting of the leaves of milo in contrast to either the corn or kafir usually could not be observed until much later in the day. The increase in the rate of loss of leaf water in the milo from 1 to 3 p. m. would indicate that the rate of absorption of water from the soil during that period was less than the loss by evaporation from the leaves.

VARIATION OF THE DRY MATTER

The amount of dry matter in the leaves of milo was at all times greater than in the leaves of corn or kafir of the same age. If we take the average weight of a square meter of corn leaf as 1, the average weight of an equal area of leaf would be 1.08 for kafir and 1.16 for milo. These differences in weight could be due either to the more compact arrangement of the cells or to a difference in the thickness of the leaves of the three plants or to both of these factors.

The average difference between the maximum and minimum amount of dry matter in the leaves during the day from 7 a. m. to 7 p. m. was 4 gm. for corn, 4.8 gm. for kafir, and 8.0 gm. for milo. Table V shows the rate of increase in dry matter for corn, kafir, and milo in grams per square meter of leaf for each of the 2-hour periods during the day, from 7 a. m. to 5 p. m. From 7 to 9 a. m. the rate of increase in dry matter for each square meter of leaf was 2.2 gm. for corn, 1.7 gm. for kafir, and 1.3 gm. for milo. From 9 to 11 a. m. the increase of dry matter on the same basis was 1.1, 1.2, and 1.5 gm. for corn, kafir, and milo, respectively, while from 11 a. m. to 1 p. m. the increase was 0.8 gm. for corn, 0.7 gm. for kafir, and 2.2 gm. for milo. From 1 to 3 p. m. the rate of increase was 0.7 gm. for corn, 1.3 gm. for kafir, and 2 gm. for milo, while from 3 to 5 p. m. the increase of dry matter was 0.8, 0.7, and 0.8 gm. per square meter of leaf surface, respectively, for corn, kafir, and milo. The greatest rate of increase of dry matter in the corn leaves occurred from 7 to 9 a. m. During the next 2-hour period the rate had fallen one-half. The rate continued to decrease until 3 p. m., when there was a slight increase. The rate of increase of dry matter in the leaves of milo rose gradually from 7 a. m. until 1 p. m. and then remained constant until 3 p. m., when it began to decrease. The results with the leaves of kafir were not so marked. There was a noticeable falling of the rate of increase of dry matter from 9 a. m. to 1 p. m., and then a slight increase in the rate till 3 p. m.

TABLE V.—*Average rate of increase of the dry matter for each square meter of leaf for corn, kafir, and milo during each 2-hour period of the day*

Plant.	A. M.			P. M.	
	7–9	9–11	11–1	1–3	3–5
	Gm.	*Gm.*	*Gm.*	*Gm.*	*Gm.*
Corn	2.2	1.1	0.8	0.7	0.8
Kafir	1.7	1.2	.7	1.2	.7
Milo	1.3	1.5	2.2	2.0	.8

Two explanations are possible for these results. The milo plant either manufactures food in the leaves more rapidly than the corn or kafir or the rate of translocation is higher in the latter plants. In most cases, under the conditions of these experiments, the leaves of corn were badly wilted during the greater portion of the day. The kafir leaves also wilted, but not to the extent of the corn, while the leaves of milo very seldom showed signs of wilting. The smaller increase in dry matter in the leaves of corn and kafir during the greater portion of the day in comparison to the leaves of milo is evidently due to the severe climatic conditions. The high evaporation of water from the leaves of corn and kafir exceeds the intake by the roots; and, as a consequence, the water content is lowered to such an extent as to interfere with the vital processes of the protoplasm. The rise in temperature of the leaves due to the decreased transpiration may also be a factor in lowering the photosynthetic power of these plants. The dry-matter curves in figures 1, 7, 8, 9, 10, which represent the results for July 28 and August 11, 1914, and for the four experiments in 1916, show the marked increase in dry matter in the leaves of milo in comparison to the leaves of corn and kafir.

SUMMARY

The variation of the water and dry matter in the leaves of corn and the sorghums was determined by nine experiments in 1914, two in 1915, and four in 1916. These experiments were conducted with plants of Pride of Saline corn, Blackhull kafir, and Dwarf milo which were grown in the field, either in a series of plots or in alternate rows on the same plot. Four of the experiments in 1914 extended only through the daylight hours, but all the other experiments ranged in length from 24 to 48 hours. In these experiments the water and dry matter in the leaves were determined every two hours during 22 days and 10 nights for corn and milo and during 18 days and 10 nights for kafir.

The amount of water and dry matter in the leaves of a given variety of plant was obtained for any 2-hour period from 30 leaf samples, each with an area of 1 square centimeter. A single leaf on each of 30 representative plants furnished all the samples for an experiment extending over

any desired length of time. From the results thus obtained, the amount of water and dry matter for each square meter of leaf, the percentage of water on a wet basis, and the percentage of water on a dry basis were calculated.

The amount of water in the leaves of milo was found to be much lower at all times of the day and night than that of either corn or kafir leaves at a like stage of development, while the average water content of the corn and kafir leaves at the same age was practically the same. The water content of the leaves of corn, kafir, and milo averaged 118.5, 120.0, and 107.0 gm., respectively, for each square meter of leaf during the day periods and, taken in the same order, 127.9, 132.7, and 115.5 gm. for the night periods. The average variation per square meter of leaf between the water content of the leaves during the day and night was 9.4 gm. for corn, 12.7 gm. for kafir, and 8.5 gm. for milo. The average variation between the maximum and minimum water content of the leaves from 7 a. m. to 7 p. m. was 13.8, 8.4, and 7.8 gm. for each square meter of leaf respectively for corn, kafir, and milo, while the average range between the maximum water content of the leaves during the night and the minimum amount during the day was 23.8 gm. for corn, 25.9 gm. for kafir, and 21.7 gm. for milo

During the 22 days the evaporation as measured by a Livingston porous-cup atmometer reached a maximum 18 times between 2 and 3 p. m. and 4 times between 3 and 5 p. m. In two-thirds of the observations for corn and milo and in nine-tenths of the observations for kafir the minimum water content of the leaves under the conditions of these experiments occurred from two to four hours earlier than did the maximum evaporation as measured by the porous-cup atmometers. For the rest of the observations the minimum amount of leaf water occurred at the time of maximum evaporation.

The average variation between the maximum and minimum percentage of water in the leaves on a wet basis during the day from 7 a. m. to 7 p. m. was 3.5 for corn, 3.2 for kafir, and 4.5 for milo. On the same basis the average variation between the minimum percentage of water during the day and the maximum percentage during the night was 5.4, 5.9, and 6.0, respectively, for corn, kafir, and milo. The average difference between the minimum and maximum percentage of water on a dry basis during the day from 7 a. m. to 7 p. m. was 39.5 for corn, 31.1 for kafir, and 35.9 for milo. The average range between the maximum and minimum water content on this basis during the night from 7 p. m. to 7 a. m. was 37.5, 47.5, and 40.0, respectively, for corn, kafir, and milo, while the average range between the minimum percentage of water on this basis during the day and the maximum percentage at night was 67.8 for corn, 67.2 for kafir, and 51.2 for milo.

The dry weight of a given area of milo leaf was always found to be greater than an equal area of either corn or kafir leaves at the same stage of development. The average dry weight of a square meter of leaf for all the observations made was 48.2 gm. for corn, 52.5 gm. for kafir, and 56.2 gm. for milo. The average difference between the minimum and maximum amount of dry matter in the leaves for each square meter of leaf from 7 a. m. to 7 p. m. was 4, 4.8, and 8.0 gm., respectively, for corn, kafir, and milo. The increase in dry matter began at daybreak and the maximum amount of dry matter in the leaves occurred in most cases between 2 and 5 p. m. The rate of increase of the dry matter in the leaves during the portion of the day when the climatic conditions were severe was much higher for milo than for either corn or kafir.

The results indicate that under the conditions of these experiments the sorghums and, more particularly, milo can absorb water from the soil and transport it to the leaves more rapidly in proportion to the loss of water from the plant than can corn. As a result of this ability, the sorghums can produce more dry matter for each unit of leaf area under severe climatic conditions than the corn plant.

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PLATE 3

Milo (*M*), corn (*C*), and kafir (*K*) leaves, illustrating the method used for obtaining the leaf samples for the determination of the water and dry matter.

b
a
d
c
f
e
M
C
K

A NEGLECTED FACTOR IN THE USE OF NICOTINE SULPHATE AS A SPRAY[1]

By WILLIAM MOORE, *Head of Section of Research in Economic Zoology*, and SAMUEL A. GRAHAM, *Assistant in Entomology, Minnesota Agricultural Experiment Station*

The attention of the authors was directed recently to a case of nicotine poisoning resulting from the use of greenhouse lettuce (*Lactuca sativa*). Thinking this an isolated case due to some florist's cutting his lettuce near the time of spraying with a tobacco extract, they took no further notice of this case. About a week later an entire family of nine, after eating leaf lettuce, became ill, showing distinct symptoms of nicotine poisoning. The lettuce was traced to the florist who had grown it, and further inquiry showed that his lettuce had been responsible for both cases of poisoning.

A few heads of this lettuce, crushed and distilled under alkaline conditions, gave a distillate with a distinct odor of nicotine.[2] The distillate gave characteristic reactions of nicotine when treated with mercuric chlorid, with a solution of iodin in iodid of potassium, and with a solution of mercuric and potassium iodid.

This test was carried out 12 days after the florist had sprayed his plants with a well-known commercial tobacco extract, containing 40 per cent of nicotine sulphate, using it, according to his statement, at the rate of 1 teaspoonful to 1 gallon of water. Other growers in the vicinity have used commercial tobacco extracts containing 40 per cent of free nicotine for years, even selling lettuce the day after spraying without causing any illness to the consumers. The question arose as to why the spray containing nicotine sulphate remained on the plants for 12 days, while similar sprays containing free nicotine quickly disappeared.

A COMPARISON OF NICOTINE AND NICOTINE SULPHATE

Nicotine is volatile, in fact very volatile, when one considers that its boiling point is 250° C. When sprays containing free nicotine are used, the nicotine quickly evaporates from the plant, leaving no trace when tested chemically the day after the spraying, even where used at the rate of 1 part to 100 parts of water. Fumigation with tobacco papers containing free nicotine left no trace of nicotine on lettuce leaves the morning after fumigation, even before the plants were sprinkled. Commercial

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[2] The authors wish to express their thanks to Dr. R. A. Gortner and Mr. J. J. Willaman for assistance in the chemical analysis given in this paper.

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tobacco extracts containing free nicotine are stated by the manufacturers to be for indoor use. On the other hand, commercial extracts containing nicotine sulphate are for outdoor use, the reason given by one manufacturer being that "sulphate of nicotine does not evaporate as quickly as free nicotine." McIndoo [1] claims that nicotine sulphate kills insects by its vapor in the same manner as nicotine. He mentions the death of insects from the odor and also the vapor of nicotine sulphate.

The first point in the investigation was to determine the volatility of nicotine sulphate. Pure nicotine was treated with concentrated sulphuric acid, and this mixture was then heated over a steam radiator for 15 hours to evaporate any free nicotine which might be present. The compound thus obtained was a dark-brown, sirupy mass with no odor. Later this was found to contain a number of crystals.

This compound was first tested upon house flies. One-liter Florence flasks were used as fumigation chambers. The flies were introduced into the flask and the neck closed with wire netting to prevent their gaining access to the nicotine sulphate, which was placed on a piece of filter paper suspended from the stopper. The stopper was rubber, covered with lead foil to prevent any absorption of vapor. Pure nicotine under such conditions will kill house flies within three hours, but the nicotine sulphate failed to kill them within the time a house fly will remain alive in such confinement. Commercial 40 per cent nicotine sulphate killed the flies in from three to six hours. In order to test these compounds further, the common croton bug (*Blatella germanica*) was used, as it will live in such confinement for a long time. Pure nicotine killed these insects in 3½ days, while those in the flasks containing commercial 40 per cent nicotine sulphate and pure nicotine sulphate were alive and active 10 days later.

Allen [2] states that on treating a solution of nicotine sulphate with an alkali the sulphuric acid will act just as if it were uncombined. The addition of soap to the nicotine sulphate in sufficient quantities to render it alkaline would therefore free the nicotine. The nicotine sulphate in one flask was rendered alkaline with soap, and it was then found that cockroaches in this flask died in the same length of time as those treated with pure nicotine. From these results it would appear that nicotine sulphate was nonvolatile. To test this point further, an attempt was made to distill the pure nicotine sulphate with steam. The result of this test was negative. On rendering the nicotine sulphate alkaline and again distilling with steam, the nicotine passed over in abundance. The distillation of commercial 40 per cent nicotine sulphate with steam showed that these preparations contain from 1 to 2 per cent of free nicotine.

[1] McINDOO, N. E. EFFECTS OF NICOTINE AS AN INSECTIDE. *In* Jour. Agr. Research, v. 7, no. 3, p. 89–122, 3 pl. 1916. Literature cited, p. 120–122.

[2] ALLEN, A. H. COMMERCIAL ORGANIC ANALYSIS . . . v. 3, pt. 2, p. 183. Philadelphia, 1902.

These tests show that nicotine sulphate is relatively, if not absolutely, nonvolatile. The death of the flies in the experiment with commercial 40 per cent nicotine sulphate was due to the vapor from the small amount of free nicotine contained in these extracts. This quantity of free nicotine is apparently not sufficient to kill the croton bug.

McIndoo [1] apparently was working with commercial nicotine sulphate, and the odor and vapor of nicotine sulphate that he speaks of is really the odor and vapor of the free nicotine contained in these commercial extracts. If the death of the insects when sprayed with tobacco extracts is due entirely to the penetration of the vapor of the nicotine into the body of the insect, as claimed by McIndoo, then commercial tobacco extracts containing nicotine sulphate are really ineffective unless the nicotine is freed by rendering the solution alkaline. A small quantity of commercial tobacco extract was heated for a short time to evaporate the free nicotine. This extract was then made into a spray, using 1 part to 100 parts of distilled water. Chrysanthemums were thoroughly sprayed with this solution, killing about 40 to 50 per cent of the chrysanthemum aphids (*Macrosiphum sanborni*) infesting the plants. A portion of this solution was then rendered alkaline with sodium carbonate and used to spray other chrysanthemums. The alkaline solution killed 100 per cent of the aphids. This experiment was repeated, using pure nicotine sulphate and snapdragons (*Antirrhinum* spp.) infested with aphids (*Myzus persicae*). The solution of nicotine sulphate in distilled water killed less than 1 per cent of the aphids, probably only those knocked off the plant in spraying. Later, after the plants had been watered with tap water, a number (probably between 20 and 40 per cent) of the aphids on these plants died. This water was alkaline and apparently set free some of the nicotine, as a distinct odor of nicotine was noticed. The same solution of pure nicotine sulphate was rendered alkaline with sodium carbonate, to free the nicotine, and used on the snapdragons, when 100 per cent of the aphids were destroyed.

By titrating spray solutions containing commercial 40 per cent nicotine sulphate at the rate of 1 part to 1,000 parts of water it was found that the tap water at this Station would decompose about one-half of the nicotine sulphate contained in the solution. The addition of soap at the rate of 1 pound to 100 gallons of water broke down the rest of the nicotine sulphate. These results, however, will vary according to the alkalinity of the water, the amount of alkali in the soap, and the brand of commercial nicotine sulphate used.

The above facts probably explain the different results obtained in the use of tobacco extracts, and also why soap greatly increases the efficiency of sprays containing nicotine sulphate. Inasmuch as the vapor of nicotine is the principal cause of the death of insects in spraying with tobacco

[1] McIndoo, N. E. Op. cit.

extracts, the maximum efficiency of those containing nicotine sulphate can only be obtained by insuring that the spray gives at the time it is used an alkaline reaction. This may be obtained by the use of hard water, the addition of soap, or in some cases by the addition of a sufficient amount of sodium carbonate or lime water to produce an alkaline reaction.

The fact that nicotine sulphate is nonvolatile explains the cases of poisoning from eating lettuce sprayed with tobacco extracts containing this material. The only chance of removing nicotine sulphate from the lettuce leaves would be by dissolving it off in the water used in sprinkling. After sprinkling, the lettuce leaves are covered with drops of water in which the nicotine sulphate is held in solution. When these drops evaporate, there is a possibility of the nicotine being absorbed into the tissues of the leaf. This possibility is shown by the fact that, after several thorough sprinklings of the lettuce in the greenhouse, the plants will still show by chemical analysis slight traces of nicotine. In the experiments cited in this paper a slight burning of the foliage resulted from the use of nicotine sulphate, but not with free nicotine.

SUMMARY

(1) Nicotine sulphate is nonvolatile.

(2) Alkalies contained in hard water and soap set free the nicotine contained in nicotine-sulphate sprays.

(3) In order to obtain the maximum efficiency of tobacco extracts containing nicotine sulphates, they should be rendered alkaline before using.

(4) Commercial tobacco extracts containing nicotine sulphate should not be used in the greenhouse, at least not on plants which are later to be used for food.

(5) Tobacco extracts or tobacco papers containing free nicotine may safely be used in the greenhouse on plants such as lettuce, without endangering the lives of the consumers.

(6) Food plants such as lettuce sprayed with tobacco extracts containing free nicotine should not be cut for the market until the day after spraying. If the temperature of the house is low, a longer period should be given the nicotine to evaporate from the leaves.

A NEW DISEASE OF WHEAT

By Erwin F. Smith,

Pathologist in Charge, Laboratory of Plant Pathology, Bureau of Plant Industry, United States Department of Agriculture

The appearance in our Middle West of a new disease of wheat (*Triticum* spp.) is a matter of much concern. It is yet too early to map its distribution, but it has appeared in parts of Indiana, Arkansas, Kansas, Oklahoma, and Texas, and is believed to be present in other States.

I have been aware of the existence of this disease since 1902, having that year received a few diseased wheat spikelets from Indiana (courtesy of Dr. J. C. Arthur) with the statement that the inclosed might be of interest to me. It was then identified as probably a bacterial disease, but was not supposed to be one of any great importance. Since that year I heard nothing more concerning it until 1915, when abundant material was received in June from Kansas (courtesy of Mr. Leo E. Melchers), and again from Indiana (courtesy of Dr. H. B. Humphrey, of Cereal Investigations, Bureau of Plant Industry).

This year (1917), owing to the great slump in the yield of winter wheats in our Middle West (estimated at 150,000,000 bushels, and generally ascribed to winter-killing), I suspected that a part of the loss might be due to this new disease, and have sent three men into Texas, Oklahoma, Kansas, Arkansas, Missouri, and neighboring States to make an exploration. From each of these men I have received hard wheats showing the disease.

From the fact that it occurred in Indiana 15 years ago, it seems probable that this disease has existed in our wheat fields for many years unrecognized, either altogether overlooked or, what is more likely, confused with other wheat diseases. First, in 1915, probably under specially favorable weather conditions, it developed to such an extent as to attract general attention and frighten many farmers, especially in Kansas.

From the little we yet know it is not possible to predict its future course nor to pronounce positively as to its cause, although from the number of bacteria present in the spots, bacteria which are sometimes so abundant as to ooze to the surface in honey-like small drops, drying as crusts, and from the fact that the poured plates this year have yielded the same organism as in 1915, I believe it to be of bacterial origin. Should it increase, or even continue to prevail as extensively as in 1915 and this year, it will have to be reckoned with as a very serious disease of wheat, not as destructive as the rusts but more destructive than the

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smuts and very likely more difficult to control. On the contrary, if its recent prevalence has been due to very exceptional meteorological factors, such as the warm weather in May and June of 1915 associated with frequent rains or heavy dews, then we may expect it to be much less prevalent in years when these conditions do not prevail. I am inclined to take a serious view of the situation because the disease attacks not only the leaves, glumes, awns, rachis, and stalk of the wheat plant, thus sapping the vigor of the whole plant, but sometimes also the kernel itself, thereby suggesting (as already proved for maize attacked by *Bacterium stewarti*) that it is carried over from year to year on the seed.

A careful study of the disease is under way in the Laboratory of Plant Pathology to determine the biology of the parasite and whether it is actually transmitted from the seed to the young plant and so again to the seed, as I suspect. I have also entered into cooperation with the Kansas and the Wisconsin Experiment Stations for the further study of this disease. This study will require considerable time, and it is desired here only to call attention to some of the conspicuous signs of the disease and to ask for samples of it from Station workers and others in all parts of the United States, together with reports concerning its prevalence, that we may know as speedily as possible its distribution and the extent of the danger.

The principal signs on the ripening grain are as follows:

CHAFF.—In late stages, as the wheat approaches maturity, black, longitudinal, parallel, more or less sunken stripes occur which, as a rule, are more numerous and conspicuous on the upper parts, where they often fuse, but which also often extend to the base of the glume. Internally, in the parts corresponding to the stripes, the glumes are black- or brown-spotted and swarming with bacteria, but sometimes, at least, fungi are also present. In bearded wheat the beards are often attacked and browned, at least in their basal parts.

RACHIS AND STALK.—In late stages these are both conspicuously brown- or black-striped.

LEAVES.—In 1915 I did not see the disease on the leaves, not many leaves having been sent me, but from what I have seen this year I know that they also are attacked (Pl. 4, fig. 3).

KERNELS.—When the disease is serious, the kernels are badly shriveled, and, in some cases at least, they show small cavities occupied by bacteria.

WHOLE PLANT.—The result of this disease is a dwarfing of the spike and a very marked shriveling of the kernels, with corresponding reduction of the yield.

Plate 4, figures 1 and 2, from Kansas wheat (crop of 1915) shows the black striping on the glumes and rachis, and Plate 8 shows the common shriveling of the kernels.

Plate 5 is of wheat from Fort Worth, Tex. (crop of 1917).

Plate 6, figure 2, and Plate 7, from Arkansas wheat (crop of 1917) show black glumes, twisted awns, and bacterial ooze from the rachis and from the stems.

Based on what I have seen, two tentative pieces of advice may be offered:

(1) Use, this autumn, seed wheat derived only from fields known to have been free from the disease.

(2) Avoid the use of manure from animals fed on or bedded on diseased straw. Such manure should be used only on fields not intended for wheat or other grains. Animals pastured on diseased wheat stubble should not have the range of fields designed for the next crop of wheat.

It is hoped that by the middle of August of this year sufficient data may be in hand to make a definite statement as to the cause of the disease, the localities where it occurs, the approximate losses due to it, its method of distribution—that is, whether on the seed or not—and the best means for holding it in check, if any can be found.

PLATE 4

1, 2.—Spikes magnified to show more distinctly the dark blotches and stripes which are signs of the disease. Kansas, 1915. Bacteria present.

3.—Outer surface of a leaf sheath showing black spots and stripes occupied by bacteria. No. 153. Farmington, Ark., 1917.

PLATE 5

Spikes magnified to show black stripes on glumes and awns. Fort Worth, Tex., 1917. No. 97. Bacteria present.

PLATE 6

1.—Black stripes on glumes, awns, and rachis. Rhome, Tex., 1917. No. 171. Bacteria present.

2.—Spikelets aborted and blackened, awns twisted, rachis badly diseased (blackened or water-soaked in appearance and oozing bacteria). Farmington, Ark., 1917. No. 153.

1
2

1
2
3

PLATE 7

1.—Rachis black and oozing honey-yellow bacterial slime which dries as pale yellowish or whitish crusts. The awn at the left is also black in spots. Farmington, Ark., 1917. No. 155.

2, 3.—Same disease on upper part of culm showing as dark spots or stripes oozing pale-yellow masses of bacteria. Farmington, Ark., 1917. No. 153.

PLATE 8

Shriveled kernels from a single head of wheat like those shown on Plate 4. Not one berry is plump, and many are badly shriveled. Kansas, 1915. Enlarged, × 6½.

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A STUDY OF THE RATE OF PASSAGE OF FOOD RESIDUES THROUGH THE STEER AND ITS INFLUENCE ON DIGESTION COEFFICIENTS

By P. V. EWING, *Animal Husbandman*, and F. H. SMITH, *Chemist, Georgia Agricultural Experiment Station*

INTRODUCTION

As a result of some earlier investigations conducted at this Station [1] on the association action of feeds, it was found that the digestibility of the crude fiber of some feeds was apparently lowered when these were fed in a ration containing certain other feeds. Our observations also indicated that these influencing feeds caused an increase in the rate of food passage through the steer. A study of the data obtained from these earlier feeding trials suggested that there might be a correlation between the time required for the passage of the food through the animal and the moisture content of the feces.

Studies have been made on this earlier work with attention directed especially to the relationship between the moisture content of the feces and the digestion coefficients; and, in addition, essentially the same digestion experiments have been repeated and similar comparisons made upon these data. An attempt was made to follow more closely and directly by means of rubber markers the time required for passage of the food residues through the steers. Further efforts were made to determine the rate of passage by means of calculations based upon the intake of food and outgo of feces and the alimentary-tract contents as ascertained on slaughtering. Thus, three methods have been employed in studying the rate of passage of food residues and the influence on the digestion coefficients.

I.—MOISTURE CONTENT OF THE FECES

Although an expression for the exact time required for the passage of food residues can not be obtained from the determination of the moisture content of the feces, direct comparisons may be made of the relation

[1] EWING, P. V., AND WELLS, C. A. THE ASSOCIATIVE DIGESTIBILITY OF CORN SILAGE, COTTONSEED MEAL, AND STARCH IN STEER RATIONS. Ga. Agr. Exp. Sta. Bul. 115, p. 269–296, 7 diagr. 1915.

between the moisture content and the coefficients of digestion. Upon the assumption that a high moisture content of the feces accompanies a more rapid rate of passage, comparative values may be obtained for the time of passage. To avoid the complications in the calculations and results which would arise if comparisons were made of the data obtained while on different rations, we have made our studies on the correlations between the high and low moisture contents of the feces and the corresponding digestion coefficients where the same rations were employed. In Table I these results, as obtained from two series of digestion trials, both of which were made in duplicate, are given. Correlations were then made between the digestion coefficients and the moisture content of the feces. Arranged in table form we have the kind of correlation for each ration as indicated in Table I, no sign being used in those instances where contradictory results for the two series were obtained.

TABLE I.—*Correlation between the moisture content of the feces and digestive coefficients*

Ration No.	Composition of ration.			Dry matter.	Ash.	Nitrogen.	Crude fiber.	Nitrogen-free extract.	Fat.
	Silage.	Cotton-seed meal.	Starch.						
	Per cent.	*Per cent.*	*Per cent.*						
1	100.0	0.0	0.0	.....	.....	−	.....	+	.....
2	0.0	100.0	0.0	+	+	.....	.....	+	.....
3	70.0	30.0	0.0	+	+	.....	.....	.....	−
4	50.0	50.0	0.0	+	+	−	+	.....	.....
5	34.5	34.5	31.0	.....	.....	−	+	+	−
6	69.0	0.0	31.0	.....	−	+	+	.....	.....
7	30.0	70.0	0.0	+	+	.....	+	+	.....
8	15.8	36.9	47.3	.....	+	−	.....	−	−

While in the cases of the ash, nitrogen, and nitrogen-free extract the results do not always agree, the indications are that, with a higher moisture content of the feces, there is a more complete digestion of all nutrients except nitrogen and fat. According to Kellner,[1] the occurrence of nitrogenous and ether soluble substances in the feces is attributable largely to metabolic processes, mucus, intestinal epithelium, microorganisms, and especially to the content of the digestive juices, notably the bile. Since a high moisture content of the alimentary tract comes from the copious secretion of the digestive juices, it results naturally that we should have a more complete digestion of most nutrients, with a high moisture content of the feces, and also that the excessive nitrogen-containing and ether-soluble compounds of the feces should indicate a decrease in the digestion of these nutrients.

[1] KELLNER, Oskar. DIE ERNÄHRUNG DER LANDWIRTSCHAFTLICHEN NUTZTIERE . . . Aufl. 6, p. 32. Berlin, 1912.

II.—USE OF RUBBER MARKERS

In order to determine more accurately the influence exerted on the digestion coefficients by the rate of passage of the food residues, it was necessary to develop a method by which we could determine with a fair degree of accuracy the time required for the passage of the food residues through the animal, a problem much more difficult in the case of ruminants than in the case of animals with simple stomachs. So far as the available literature shows, little study has been made on this problem as applied to farm animals. Guernsey and Evvard [1] have done some work along this line with swine at the Iowa station. With swine very good results can be obtained by the use of either bone black, carmine, finely ground charcoal, or of bismuth subnitrate or other bismuth compounds, as indicators by feeding at a specified time and noting the time of their first appearance in the feces as manifested by discoloration. Indicators dependent on change of color in the feces can not be used on ruminants, cattle in particular. In some manner they seem to "wash" ahead of the feed and show an abnormally rapid passage. In order to get a marker applicable to ruminants, we experimented with soft rubber disks cut from heavy rubber tubing. One hundred of these were fed at the beginning of a 10-day digestion trial and a count was made of them as they appeared in the feces. By finding the number that appeared during each 12-hour period we expected to obtain a fairly accurate measure of the time required for the passage of the food residues. The number of rubbers appearing up to 48 or 72 hours after feeding, for example, should represent a measure of the feed fed at the same time as the rubbers which had passed through. Some of the indicators appeared within 12 hours, while others were recovered as late as 60 days following, and still others never came out until the steers were slaughtered.

The above-described plan of feeding markers with the ration was followed out, using the same rations given in Table I. An attempt was made to retard or hasten the passage of the food by feeding 60 or 120 gm. of calcium carbonate or magnesium sulphate so that the variations in time required for passage of the food residue might be more marked even on the same ration. Naturally with the use of such small amounts no great variations would occur either in the time required for passage or the moisture content of the feces. This was observed when either of the two salts was fed. In order to determine what effects the substances would have upon the digestion coefficients, comparisons were made between the coefficients of each of the eight rations when fed with 120 and 60 gm. as against those obtained when none was fed. As well as could be determined, there was very slight variation in the moisture content of the feces; and, with the exception of a lowering of the

[1] GUERNSEY, S. C., AND EVVARD, J. M. THE DIGESTIBILITY OF MAIZE CONSUMED BY SWINE. *In* Biochem. Bul., v. 3, no. 11/12, p. 369–372. 1914.

apparent digestibility of ash, which was observed when calcium carbonate was fed, the variation in the digestion coefficients was not greater than could be accounted for on the basis of the dry-matter content of the feces.

After careful and extensive feeding trials, it was found necessary to abandon the use of rubber markers for determining the time for passage, since the method had proved unreliable in each of the experiments. On some of the rations the rubbers apparently passed through with the feeds, while on other rations they either passed through ahead of the food mass or were retained in the alimentary tract during an abnormally long period. When the particles of the feed resembled the rubbers in size, the markers would pass through with the feeds, but when there were no coarse particles of feed in the ration, as in the case of rations made up of cottonseed meal and starch, the rubber markers were passed in some instances, while in others they were not. Furthermore, on the same rations the extent to which the markers passed through seemed partially dependent on the moisture content of the feces.

III.—SLAUGHTER TESTS

A third method was used, based upon a digestion trial followed by a slaughter test. A measure of the time required for the passage of the residue of the feed was obtained by dividing the food and fecal dry-matter content of the alimentary tract by half the sum of the dry matter ingested and excreted per given unit of time. The inaccuracies of the method, arising from certain metabolic processes, are recognized; but their influence would be no greater on these results than on the digestion coefficients, if as much. The data obtained from the digestion trials are summarized in Tables II, III, IV, and V.

TABLE II.—*Results of the digestion trials*

Steer No.	Date.	Weight of steer.	Percentage of silage and cottonseed meal in ration.		Silage fed daily.	Cottonseed meal fed daily.	Dry matter of feed.	Average dry matter in feces (daily).
			Silage.	Cottonseed meal.				
	1916.	*Kgm.*	*Per cent.*	*Per cent.*	*Kgm.*	*Kgm.*	*Kgm.*	*Kgm.*
52.....	May 31	385	40	0	6.848	.....	1.6565	0.8206
49.....	June 3	380	60	0	10.270	.....	2.6340	1.2446
46.....	8	362	40	60	6.848	2.016	3.4730	1.5022
45.....	11	385	60	40	10.270	1.338	3.8400	1.5186
44.....	Apr. 27	395	0	60	.....	2.016	1.8170	.5231
53.....	May 29	358	0	40	.....	1.338	1.2060	.3450

TABLE III.—*Results of slaughter tests*

Steer No.	Gross contents.	Dry matter of contents.	Percentage of dry matter in contents.	Dry matter over 2 mm.	Dry matter under 2 mm.	Percentage of dry matter over 2 mm.	Percentage of dry matter under 2 mm.
	Kgm.	*Kgm.*		*Kgm.*	*Kgm.*		
52	67.000	6.490	9.69	2.410	4.080	3.59	6.10
49	70.760	7.260	10.26	3.135	4.125	4.43	5.83
46	64.714	8.358	12.92	2.930	5.428	4.53	8.39
45	65.460	8.382	12.80	3.965	4.417	6.05	6.75
44	60.424	3.670	6.07	.000	3.670	.00	6.07
53	36.581	2.269	6.20	.000	2.269	.00	6.20

TABLE IV.—*Calculation of time required for food passage*

Steer No.	Daily intake of dry matter.	Daily outgo of dry matter.	Half-intake+ half-outgo.	Dry matter of steer contents.	Time required for food passage.
	Kgm.	*Kgm.*	*Kgm.*	*Kgm.*	*Days.*
52	1.6565	0.8206	1.2386	6.490	5.24
49	2.6340	1.2446	1.9392	7.260	3.75
46	3.4730	1.5022	2.4876	8.358	3.36
45	3.8400	1.5186	2.6793	8.382	3.13
44	1.8170	.5231	1.1701	3.670	3.14
53	1.2060	.3450	.7755	2.269	2.92

TABLE V.—*Average digestion coefficients of the nutrients of the several rations as determined by several digestion trials, showing gains or losses in cases of compound rations where the gain or loss results from the combination*

Ration No.	Percentage of silage and cotton seed meal in ration.		Dry matter.	Ash.	Nitrogen.	Crude fiber.	Nitrogen-free extract.	Fat.
	Silage.	Cotton-seed meal.						
	Per cent.	*Per cent.*						
1	40	0	50.45	80.1	87.1	75.0	39.2	64.2
2	60	0	52.74	44.8	88.8	70.4	44.8	65.8
3	40	60	56.78	52.2	83.4	44.3	53.7	90.7
Gain or loss			−4.62	+12.4	−0.9	−28.6	+4.1	−0.7
4	60	40	59.70	59.7	52.1	87.0	60.2	85.7
Gain or loss			+1.10	+21.1	+0.6	−14.6	+10.7	−1.7
5	0	60	71.25		81.9	61.0	63.6	96.6
6	0	[a] 40	71.25		81.9	61.0	63.6	96.6

[a] Coefficients derived from results on this ration are unreliable, so that figures given are those obtained on the higher cottonseed-meal ration.

The primary object of the slaughter test was to obtain the dry-matter content of the alimentary tracts of the steers; but incidentally observations were made upon the size of the particles of food residue in the various organs, from which evidence was obtained corroborating that fur-

nished by the rubber markers and which had indicated that the larger or coarser particles of food required a longer time for passage through the animal than the finer particles.

From the data presented in Table IV we were able to obtain a reliable expression for the average time required for the passage of the food residues through the animal. With the rations used and the quantities fed the time varied from 2.9 to 5.2 days. The two most important factors determining the rate of passage are the nature of the ration and the amount fed. Coarse roughages seem to require a considerably greater time than the more finely ground concentrated feeds, this holding true even when the two kinds of feeds are consumed together, as has been shown in a previous publication.[1] As to the influence of quantity, it appears that, when the coarse feeds were fed, a smaller quantity required a greater time for passage of the residues; but, when the feed was a concentrate in pulverized form, the variation was not so pronounced. Of these two factors the nature of the food seems to be of the greater importance in influencing the rate of passage of the residues through the steer.

A valuable study might have been made between the rate of passage as ascertained by means of the slaughter tests and the moisture contents of the feces. Such a comparison is not of value with the rations used, since varying quantities of foods were used, and the effect produced on the moisture content of the feces by the quantity of food consumed has not yet been determined.

In dealing with the influence which the rate of passage of the feed residue may have had on the digestion coefficients we are unable definitely to attribute changes to the rate of passage; and at best it can only be said that associated with the more rapid passage there occurred an apparent gain in the digestibility of the ash, negligible results in the case of nitrogen, a decided loss in the digestibility of the crude fiber, a gain in the case of the nitrogen-free extract, and negligible results in the case of fat. The loss in digestibility of crude fiber was sufficient to overbalance the gains made by the other nutrients, and resulted in a slight decrease in digestibility of total dry matter, with a more rapid passage. These findings do not agree entirely with results obtained when the comparisons were made between the digestion coefficients and the moisture content of the feces, the greatest variation being in the case of the crude fiber. Although a gain in crude-fiber digestion was indicated when the moisture content of the feces was high, a loss was indicated under the third method, where there is a direct measure of the rate of food passage. Crude-fiber digestion is largely a biochemical digestion in which the time element is of importance, and it seems more tenable to assume that we have a less complete digestion of crude fiber if the time of digestion is shortened by a more

[1] EWING, P. V., WELLS, C. A., and SMITH, F. H. THE ASSOCIATIVE DIGESTIBILITY OF CORN SILAGE AND COTTONSEED MEAL IN STEER RATIONS. PART 2. Ga. Agr. Exp. Sta. Bul. 125, p. 149–164, illus. 1917.

rapid passage of the crude fiber through the animal. While Table V indicates no change in the digestion of nitrogen and fat, it should be pointed out that the actual digestion of these nutrients was probably increased by the more rapid movement through the animal. This increase was probably counterbalanced by the metabolic nitrogen and fat residues accompanying the greater flow of digestive juices when the passage of the food residue was more rapid.

DISCUSSION OF RESULTS

The differences attending the accurate measurement of the time required for the passage of food residues has retarded studies along this line although the question is one of considerable importance. In the work reported here only the last method can be considered as offering direct results, although the two other methods were of value. From the standpoint of the specific problem the weakness of the first method is in that it still remains to be proved definitely that the rate of passage of feed residue through the steer can be measured by the moisture content of the feces. Our work has shown that, if a high moisture content of the feces is indicative of rapid passage, then the apparent digestion is more complete probably for all the nutrients with the more rapid passage and less complete with the slower movement. Unfortunately the method of study shows only the relationship and not the extent of the variation in digestion associated with a high moisture content. These results are in accord, however, with cattle-feeding practice, in that cattle are not considered as doing best or making the most of their food unless the feces has a certain semiliquid consistency and has a strong odor of bile. Practical feeders have long realized the advantage of feeding some slightly laxative feeds at all times if the best results are to be secured from the feeding.

In making a closer examination of Table I and the results given there it is interesting and probably of significance to note that the variation, or contradictory results obtained (indicated in the table by the omission of the positive or negative sign), occurred with those rations that might be considered as abnormal. One of these rations contained 31 per cent of cornstarch and 69 per cent of silage, while the other contained 47.3 per cent of starch.

In the case of the second method, which proved impractical for the main object sought, the experiments showed that some solid particles of the feed might remain in the steer as long as 60 days, or even longer. The slaughter tests made later showed that hard particles of feed and foreign substances were especially prone to become delayed in transit either in the reticulum, in the fourth, or true, stomach, or in the first few ventral folds of the duodenum. The coarse feeds and roughages retard the rate of passage of feed residues, a point proved conclusively by the slaughter tests.

It was only by means of the slaughter test that we were enabled to arrive at an accurate measure of the specific time required for the passage of a certain ration residue through the steer. As already stated, the residue from any given feeding may require for its complete expulsion several weeks, or even months. The figures obtained express the average time required for passage, the calculation being based upon the dry matter of the feeds, the content of the digestive organs, and the resultant feces. Expressed as a formula:

$$\text{Time} = \frac{\text{Amount}}{\text{Rate}}, \text{ or } T = \frac{C}{\frac{R+F}{2}}$$

in which T represents time units required for passage of food residue, C the dry-matter contents of the alimentary tract of the steer as determined at the time of slaughter, R the dry-matter content of the ration per given unit of time, and F the dry-matter content of the feces voided for the given unit of time.

In making use of this formula it is recognized that certain end products of digestion, such as residues from digestive juices, cell destruction, and bacterial life, may interfere with the accuracy of the method; but the interference can be no greater than in the case of the determination of digestion coefficients, which are influenced by the same factors when the usual method of determination is employed.

Among other things the greater length of time required for the passage of food residues in the case of the coarser feed was noticeable. Likewise, where the ration or feed is the same, a greater time will be required for the passage of residue from the smaller quantity. In the cases of the two compounded rations, which might be classed as normal rations, the rate of passage of feed residues did not vary a great deal and were between 72 and 84 hours, which might be taken as the average time required for the passage of feed residues through steers on normal rations. The third method of study shows that it is quite probable that, associated with a more rapid passage of feed residue, we have a more complete digestion of all nutrients except crude fiber. Therefore, in actual feeding practice it is desirable that a rapid passage of feed residues be encouraged, since any loss in crude-fiber digestion may be a net gain in energy units on account of the high cost in energy for the digestion of this nutrient.

CONCLUSIONS

(1) In general, a more complete digestion is associated with a more rapid passage of feed residue through the steer.

(2) Crude-fiber digestion seems to be decreased with a more rapid passage of feed residues.

(3) Coarse feeds and roughages retard the rate of passage of residues.

(4) Finer particles of feeds and finer ground feeds pass through the animal more rapidly than the coarser ones.

(5) An increase in the quantity of feed consumed causes an increase in the rate of passage of feed residue.

(6) The greater the capacity of the alimentary tract of the animal the longer the time required for the passage of feed residues.

(7) The determination of the rate of passage of feed residues through steers by means of feces markers or color indicators is not feasible.

(8) Doses of calcium carbonate and magnesium sulphate in quantities of 60 or 120 gm. per steer daily exerted no appreciable influence on digestive coefficients.

(9) The average specific time required for the passage of the feed residues on a normal ration probably varies between 72 and 84 hours.

(10) The rate of passage of feed residue is influenced largely by the nature of the ration and by the quantity, the importance of the two influencing factors being in the order named.

A FURTHER CONTRIBUTION TO THE STUDY OF ERIOSOMA PYRICOLA, THE WOOLLY PEAR APHIS

By A. C. BAKER, *Entomological Assistant,* and W. M. DAVIDSON, *Scientific Assistant, Deciduous Fruit Insect Investigations, Bureau of Entomology*

In the present paper, in which the complete life cycle of *Eriosoma pyricola* is given, it seems best to discuss somewhat fully the history of the different species recorded on pear roots (*Pyrus communis*). This is especially urgent since complete life studies of the woolly pear aphis have shown that the spring forms as present on elms are remarkably different from the fall forms upon pear roots; in fact, one of the chief characters used in the separation of the species does not exist in the spring forms at all. This is remarkable in view of the fact that this same character, the wax pores, has been the chief one in linking the different forms of other species closely related to the root aphis of the pear.

SYSTEMATIC DISCUSSION

In 1849 Westwood (10)[1] described and figured the work of an aphid on Nelis d'Hiver pear. This injury consisted of knotty growths and swellings on the branches very similar to those produced by the woolly apple aphis, *Eriosoma lanigerum* (Hausmann). A short description and figures of the insect were given with the statement that the species "may be called *Eriosoma pyri.*" The woolly apple aphis is known commonly to affect pear trees above ground, while the woolly pear aphis is met only upon the roots. It seems extremely probable, therefore, that the form described by Westwood was none other than the common woolly apple aphis. This, however, the writers have been unable to prove definitely.

In 1851 Fitch (4) described an aphid from apple roots under the name "*Eriosoma pyri.*" The author stated that this species formed galls upon the roots. Since the work which Fitch credited to his *E. pyri* was very similar to that of the woolly apple aphis, if indeed not the work of that species, Fitch's *E. pyri* was later considered to be the same as *E. lanigerum* (Hausmann). A large aphid, a species of Prociphilus, occurs upon the apple in the Eastern States, and is not uncommonly found upon the pear, the fall migrants and sexes being usually seen upon those trees. The senior writer (1) has shown, from an examination of Fitch's types, that this form is the one described by Fitch as *E. pyri.* In this paper by the senior writer the species is redescribed as *Prociphilus pyri* (Fitch). The description of the earlier form by Westwood (10), how-

[1] Reference is made by number to "Literature cited," pp. 73–74.

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ever, makes Fitch's name, since a homonym, unavailable. The writers therefore propose the name "*Prociphilus fitchii*" for this species.

Another species of the same genus, *P. corrugatans* (Sirrine), occurs upon pear foliage, causing the leaves to curl. All of these species, however, are quite different from the woolly pear aphis.

Goethe, in 1884, (5) described a form occurring upon pear roots which he considered to be a variety of the woolly apple aphis, *Eriosoma lanigerum*. He called it by the varietal name of *pyri* and stated that it lives upon pear roots throughout the year. In the fall, according to this author, winged forms are produced which fly to the underside of the leaves in order to deposit the sexes. The female after fertilization lays one egg upon the pear tree. No further observations were made into the life history, so far as the forms from the egg are concerned.

Mordwilko, in 1901 (7), stated that he had examined the form from pear roots described as *E. pyri* by Goethe, and was convinced that it could not be considered as a variety of *E. lanigerum*, but must be treated as a good and distinct species. He therefore elevated the *pyri* of Goethe to specific rank, and this name has been commonly used by European workers for the root aphis which attacks pears.

In 1841 Hartig (6) described a species of aphid found producing sac-like galls on elm trees under the name of *E. lanuginosa*. This species has been redescribed and figured by several European students and its work has become well known in the European countries of the continent, as well as in the British Isles. It would seem from the statements of Tullgren (9) that the species does not occur in the Scandinavian peninsula. In America Patch (8) has figured a gall from Connecticut which was doubtfully referred to this species. No specimens were secured at the time, and no positive record, therefore, was made.

In Europe, where the life of *E. lanuginosa* on the elm (*Ulmus* spp.) has been followed, its biology has been well understood and carefully studied. Some of the earlier writers held incorrect views in regard to the sexes and hibernation of the species, but later studies have cleared up its entire life history.

In 1914 Börner (3), acting upon the suggestion of Mordwilko, showed that the *E. pyri* of Goethe is the alternate form of *E. lanuginosa* Hartig. His experiments were made near Metz. Only a few galls were located, and the insects from these were transferred to pear trees in pots. In July two small colonies were present on the roots of the potted plants, and the insects of these colonies were the offspring of the winged forms of *E. lanuginosa*. It was thus definitely established that the European pear-root aphis, *Eriosoma pyri* Goethe, is the alternate form of the elm species *Eriosoma lanuginosa* (Hartig).

The present writers (2) have described, under the name *E. pyricola*, the American woolly pear aphis, which had before that time been thought to be the woolly apple aphis. This was done because the form did not

agree in structure with any of the known species, including *E. lanuginosa* Hartig. It was pointed out, however, that the woolly pear aphis was very close in general structure to European specimens of *E. lanuginosa*. This was shown in the following words (2, p. 358):

> The winged forms of *E. pyricola* are remarkably like those of *E. lanuginosa* Hartig. The proportions are almost exactly the same.

The marked difference in the wax pores and minor differences in the sensoria were considered as showing a very distinct species. The present studies have shown that these characters are not the same in the spring forms living on elms as in the summer and fall forms living on pear roots, but that in the spring forms they are very similar to those of *E. lanuginosa*. From the fact that in other species of Eriosoma the wax pores are constant the writers concluded that they would be constant also in the *E. pyricola* and in *E. lanuginosa*. They are not so in *E. pyricola*. Lack of fall material of *E. lanuginosa* makes it impossible to determine whether they are constant in that species or not. From the very great similarity between the spring forms of *E. pyricola* and *E. lanuginosa* the writers are led to believe that the same variation will be found between the spring and fall forms of *E. lanuginosa*. If this proves true, there will no longer be any reason for keeping the two species distinct and *E. pyricola* will become a synonym of *E. lanuginosa*.

If this supposition is correct, and it is all but proved, it will show without a doubt the following to be facts:

(1) The destructive woolly pear aphis of this country is a European insect imported into the Western States on pear stock.

(2) It has spread rapidly in the West in the last 25 years and now occurs from Washington to California, although as yet it is most destructively abundant in California.

(3) The isolated infestations in the Middle West and in the East are due to separate infested importations.

(4) While the alternate winter forms thrive best on European elms, the species is able to live successfully upon the common American elm and at no very distant date may become entirely adapted to this native tree.

(5) The species is liable through importations to gain a foothold in any pear-growing region, for, as recently as 1916, skins have been collected on seedling nursery stock.

DESCRIPTION OF ERIOSOMA PYRICOLA

STEM MOTHER.—Antennal segments with the following measurements: I, 0.048 mm.; II, 0.064 mm.; III, 0.208 mm.; IV, 0.112 mm.; V, 0.05 mm. Segment IV of antenna fully imbricated and armed with rather prominent hairs. Segment V fits close against segment IV, with little constriction, so that it does not give the general appearance of a distinct segment, although this is easily observable when looked for. The unguis comprises somewhat more than half of the segment. Form of body globose. Length

from vertex to cauda, 2.24 mm; legs short, the tibiæ being about equal in length to the antennæ.

SPRING MIGRANT.—Varies considerably in size, but the following measurements represent about the average. Antennal segments: I, 0.064 mm.; II, 0.064 mm.; III, 0.448 mm.; IV, 0.144 mm.; V, 0.1 mm.; VI, 0.08 mm. Segment III of antenna, with 25 to 30 annular sensoria on the lower surface of the segment and almost encircling it; segment IV with 7 or 8 and segment V with 5 or 6. Segment VI usually without sensoria except the permanent ones. Forewing about 2.5 mm. long and 0.96 mm. broad. Hind tibia, 0.738 mm.; hind tarsus, 0.144 mm. Legs slender.

In comparing the spring migrants of *E. pyricola* and *E. lanuginosa* some differences are encountered. These are principally in the antennæ and are shown in the accompanying illustrations, reproduced from photographs. It will be noted that the antennæ of *E. lanuginosa* (Pl. 9, *A*) are considerably heavier than those of *E. pyricola* (Pl. 9, *B*, *E*). Segments IV and V seem also to be comparatively larger and armed with more and heavier sensoria. Segment VI, as compared with V, is somewhat shorter in *E. lanuginosa* than in *E. pyricola*. There are available for study, however, only a few specimens of *E. lanuginosa*. It seems quite probable that these represent only variations in the species and that, when a long series of *E. lanuginosa* is available, specimens will be found similar to the American forms.

Specimens of fall migrants upon European pear stock (Pl. 9, *C*) are without doubt the same species as that occurring in America (Pl. 9, *D*). It is possible that these specimens are in reality the fall migrants of *E. lanuginosa*. This can be proved only by a study of reared European material, which, under present conditions, it is impossible to obtain.

DEVELOPMENT OF THE GALLS AND GALL APHIDS

In a former article (2) it has been mentioned by the writers that the fall sexuparous migrants leave the pear roots upon which they have developed and fly to elm trees to deposit the sexes on the trunks and limbs. These migrants settle on *Ulmus americana* and *U. campestris*. The latter tree is distinctly preferred; in fact, no perfect galls have been produced on the former. The sexed female after mating deposits a single egg in a crack in the bark or underneath a bud scale.

The eggs during the winter are reddish, greenish red, or greenish brown, but immediately before hatching appear grayish brown, due to the color of the embryo. The empty shell is dirty white.

From this egg hatches the young stem mother which ascends a trunk or limb and seeks an expanding leaf. In 1916 hatching commenced March 23 and extended until April 18, the majority hatching during the first two weeks of April.

The newly hatched stem mother is oval in shape, bare and shining, of a yellowish or brownish olive hue with small black eyes and hyalin appendages and beak. The thoracic region is lighter in color than the

rest of the body and the segmentation is well marked. The beak reaches about to the third abdominal segment.

This form settles on the underside of an elm leaf near the midrib and generally not far from the base. After the young aphid has fed for a very few days, the leaf begins to curl around it and the curling and twisting become more pronounced as the insect grows, so that by the time it has reached the third instar the leaf in the form of a gall has completely closed around it. This gall is a part of the leaf tissue, ribs, and parenchyma, which has developed independently of the remainder, owing to the puncture and feeding of the insect. The walls of the gall are thicker than the normal tissue, and frequently the petiole is abnormally thickened. Galls harboring immature stem mothers have the form of a compact spiral twist. On the outside they bear a thick fringe of whitish pile, and in color they vary from the normal leaf color to a pale yellowish white, often rosy tinted when exposed to much direct sunlight. Many occur which harbor more than one fundatrix, but even those with single tenants vary noticeably in size. The average diameter of galls containing third-instar fundatrices was ¼ inch.

The young stem mothers in the first instar are greenish gray with grayish "meal" on dorsum and pleura; they are elongate oval. In succeeding instars the color is slaty blue, and considerable fine whitish "wool" issues from pores; the shape becomes short pyriform, and globules of viscous honeydew are ejected from the anus.

The mature fundatrix is dark bluish green, robust, clothed with white wooly and waxy filaments, the larger of which arise from four longitudinal dorsal and dorso-lateral rows of pores; the antennæ and legs are yellowish brown; the tarsi, knees, and two distal antennal segments are dusky gray; the beak is very short, yellowish brown, with a gray tip; the dorsum of the head is gray; the eyes are black, simple, and very small; the body is globular oval, becoming greatly distended with age. Recently matured stem mothers were collected between May 17 and 23, and it was observed that several matured between these dates. Field observations indicate that this was the period in which the majority reached the adult stage. It appeared that the stem mothers fed from four to five weeks in the immature stages. The galls containing the mature fundatrices varied in diameter from ⅓ to ½ inch, and their shape was a rather short subglobular spiral. Figures *A* and *D* of Plate 10 show a gall, collected on May 13, which harbored a fourth-instar fundatrix.

Following upon the maturing of the stem mother the galls grow very rapidly and change their shape to the form depicted in Plate 10, *B*, *C*. The photographs from which these illustrations were made were taken on July 12 and present two diametrically opposite views of the same gall, which contained several hundred inmates. It should be observed that the gall is no longer closed.

At the end of May the galls were as large as ⅞ inch in diameter on large leaves, whereas those on naturally small leaves were mostly under ½ inch. During June the galls developed rapidly, assuming an oblong saclike or baglike appearance, the portions of leaf between the lateral ribs became much distended, and the ribs thickened abnormally. The external color varied from pale yellowish white to purplish brown, the majority of the galls exposed to sunlight being rosy and those in shady places light green or yellow with purplish blotches. Toward the end of June (June 21) the galls averaged 1⅛ by 1¼ inches, and specimens as large as 2¾ by 1¾ inches were observed on unusually large leaves.

By July 8 the largest specimens measured 4 by 2½ inches, the smallest did not exceed ¼ inch maximum diameter, and the average size was about 1¼ by 1⅓ inches—a slight increase in size over that existing on June 21. By the first week in July the galls have attained their full size; and, soon after having been forsaken by their inmates, they turn brown all over and become brittle but remain attached to the twigs in large numbers all through the winter succeeding (Pl. 10, *E*).

Mature galls frequently comprised the whole of a leaf, as in Plate 10, *B* and *C*, while in other instances only one side of the midrib is affected. Less frequently two or more separate galls occurred on the same leaf, and galls were more usually found on leaves at the base of the year's growth because the young stem mothers on most trees hatched at the time when the first leaves of the spring growth were unfolding, and settled on the earliest leaves. The twig illustrated in Plate 10, *B* and *C*, is an exception and occurred on a tree which threw out much of its foliage before the stem mothers hatched.

The mature fundatrix deposits young prolifically, and her body rapidly swells. Four individuals under observation deposited each about 75 young in three weeks, when the eldest matured as second-generation wingless forms (fundatrigenia). No definite records were obtained of the total progeny of the stem mothers, but it appears that they may deposit as many as 300 young during the four or five weeks in which they are alive in the adult state. It should be remarked that galls have been collected in July which contained upwards of 1,000 larvæ and pupæ, but it could not be ascertained whether these were the progeny of a single fundatrix, of several fundatrices, or the combined progeny of fundatrices and wingless viviparous females of other generations.

The newly hatched progeny of the stem mother are pink or light carmine, and elongate; the dorsum of the head is gray; the eyes are red; the thorax is light hyalin yellowish pink; the appendages and beak are hyalin whitish; the leg joints are narrowly dusky gray; the tarsi and tip of the beak are dusky gray. The larvæ remain pink during their early growth and are deeper in color after molting. During the last two immature instars the body darkens and assumes a pyriform color, but the pupæ are elongate.

The mature wingless female of the second generation is oval, dark bluish black, the body clothed with short white waxy threads (longest at the caudal extremity) and pruinose "meal" of the same color; the cornicles are black and very short; the antennæ are one-third the body in length; the antennæ and legs are bluish gray with a lilac tint, although at first pale orange; the tibæ and base of the femora are paler than the rest of legs.

The wingless forms mature in about three weeks inside the gall. In 1916 they were not at all common, as will be seen from the records which follow. They are the earliest progeny of the stem mother and apparently deposit young destined to acquire wings, as no third-generation wingless forms were ever found. Isolated individuals, when placed in empty galls, failed to deposit young or to remain where placed for more than a very few days. At the time the first wingless forms matured, pupæ occurred in the galls, and the latter must have been direct progeny of the stem mothers.

To indicate the scarcity of these second-generation wingless forms, a few observations may be cited:

On June 6 two galls were selected at random for examination of the inmates. One contained, besides the fundatrix, 6 adult wingless forms, 29 pupæ, and 250 larvæ; a second contained, besides 3 fundatrices, 31 adult wingless forms, 71 pupæ, and 531 larvæ. On July 24 a gall contained 6 dead wingless forms, 6 dead pupæ, and 63 pupal skins. During the next two weeks 3 other galls were examined without any trace of second-generation wingless forms being discovered. It might also be said that among the larvæ found in the first two galls there were very few individuals of the size and shape of a wingless form of the fourth instar. The possibility of the second generation's wingless forms leaving the parent gall and founding new galls should not be overlooked; yet the observations made indicate either that no such movement exists or that it is uncommon. Every gall examined about a month after the stem mother matured contained a small number of these wingless second generation individuals, but their production appeared to be limited to just a few of her earliest progeny.

The pupæ of the spring migrant are at first pink, and, when ready to transform, lilac, with the thoracic region suffused with light yellow. The appendages are light amber, and the wing pads pale yellowish white. They are clothed with woolly and waxy filaments, the latter arising from four longitudinal rows of dorsal and dorsolateral pores. The pupæ transform within the gall into winged parthenogenetic forms.

The spring migrants newly transformed are rich brown and soon change to their permanent dark greenish or brownish black color. The shape is elongate, and the body is shining. The general resemblance to the fall migrant is very marked. The head and thorax are shining black; the prothorax and abdomen vary from deep lilac to dark green,

rarely mottled with orange; the abdomen bears a certain amount of bluish white pubescence, and on the caudal segment is a tuft of short white "wool"; the cornicles are black, very short; the antennæ are a little over one-third the length of the body, dark greenish or yellowish brown, joints III to VI bearing transverse sensoria; the legs are light orange, the apical third to half of the femora is dark brown, the base and apex of the tibæ and the tarsi are light gray; the beak is pale yellow at base, elsewhere dark grayish brown, reaching the second coxæ; the stigma is a grayish green.

In 1916 the earliest spring migrants transformed in advanced galls exposed to maximum sunlight as early as June 8. On a young, partially shaded cork elm in the laboratory premises at Walnut Creek, Cal., the first migrants transformed on June 16, after a growing period of about 24 days. By the fourth week in June nearly every gall examined contained winged forms, and by July 10 large numbers of the earlier galls had been forsaken, all the inmates destined to acquire wings having transformed and flown off. By the end of July hardly a gall with living inmates could be found. Between June 19 and July 24, records were kept of the migrant production in three galls confined with cheesecloth on a small cork elm. Respectively, 114, 107, and 76 winged individuals issued from them; in the first case the last migrant developed on July 15, in the second on July 21, and in the third on July 24. These galls were under the average size, and, moreover, at least as many larvæ as persisted forsook the galls, probably as a result of the handling to which they were subjected. On July 17 a gall infestation, mostly on large leaves, was examined, and over a thousand pupæ and larvæ were estimated to be inhabiting the larger galls of from 2½ to 3½ inches maximum diameter. To judge by the total counts made, it is probably not an exaggeration to say that the gall of average size produced in 1916 at least 400 winged forms (migrants), and, as a heavily infested elm tree may contain as many as 400 galls, the enormous number of spring migrants produced can be imagined. Great numbers, however, were caught in spider webs on the elms; many others, including pupæ, became "choked" through the honeydew deposits within the galls, while the larvæ and pupæ suffered considerable loss in numbers through predatory insects which were able to gain admittance to the interior of the galls after the middle of June. Among these predators adults of *Scymnus* spp. (Coccinellidae) and chrysopid larvæ were most notable and abundant.

Spring migrants were observed resting on pear foliage and actively crawling up and down the lower part of pear trunks. Young deposited by them were taken in spider webs at the base of pear trees, and it appears that the young are normally deposited on pear trunks at or near to the soil surface. Spring migrants when placed in petri dishes with pieces of pear roots on wet sand deposited young which readily settled and fed upon the roots and which precisely resembled in structure—albeit

they were somewhat darker in color—the newly born larvæ of the pear-root aphis.

In confinement it was found that 12 spring migrants deposited an average complement of 22 young with a range of from 10 to 39. These were in every case deposited within three days, and in most cases within 24 hours of transforming

Root-feeding generations were bred in the laboratory at Walnut Creek, Cal., from the wingless progeny of the spring migrants, and in due course the third and fourth generations yielded a large percentage of fall migrants. These fall sexuparous migrants were bred contemporaneously with others which came from a root-feeding strain originally started in 1915.

It may be said that the young deposited by the spring migrants readily fed on pear stocks of Kieffer, French, and Japanese varieties, but, like the root-dwelling larvæ, absolutely refused to feed upon apple roots and fed only in very rare instances upon roots of the quince.

The readiness exhibited by the migrant progeny to settle on pear roots was taken advantage of in colonizing a series of young orchard trees for the purpose of later insecticide tests, and elm galls containing migrants and pupæ were buried near the roots in the soil with the result that in 75 per cent of the trees root infestation speedily resulted. This was found to be a much handier method of general colonization than the use of pieces of infested roots or the application of individuals by brush.

A diagram of the complete life cycle of *E. pyricola* is given in figure 1.

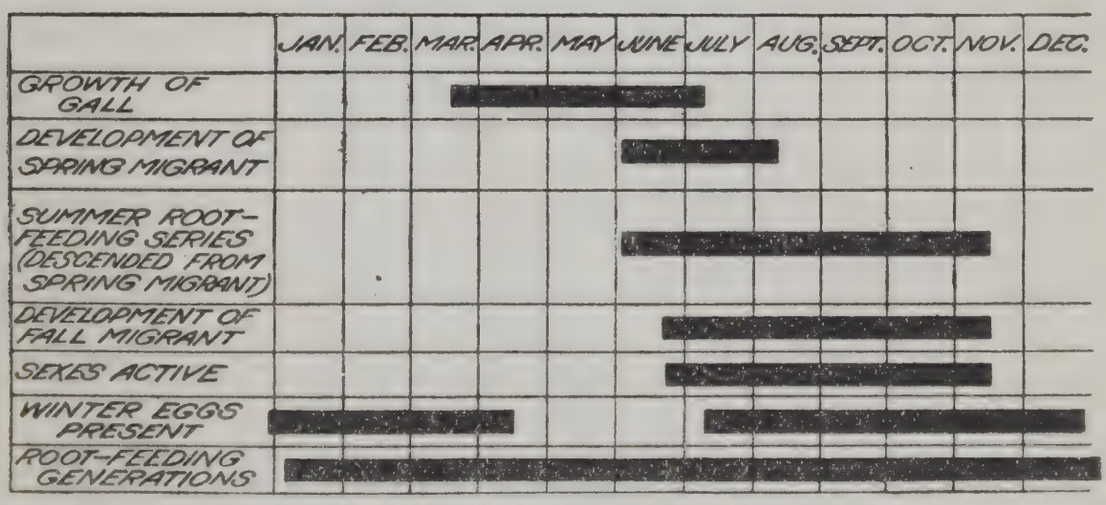

FIG. 1.—Diagram showing the life cycle of *Eriosoma pyricola*.

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PLATE 9

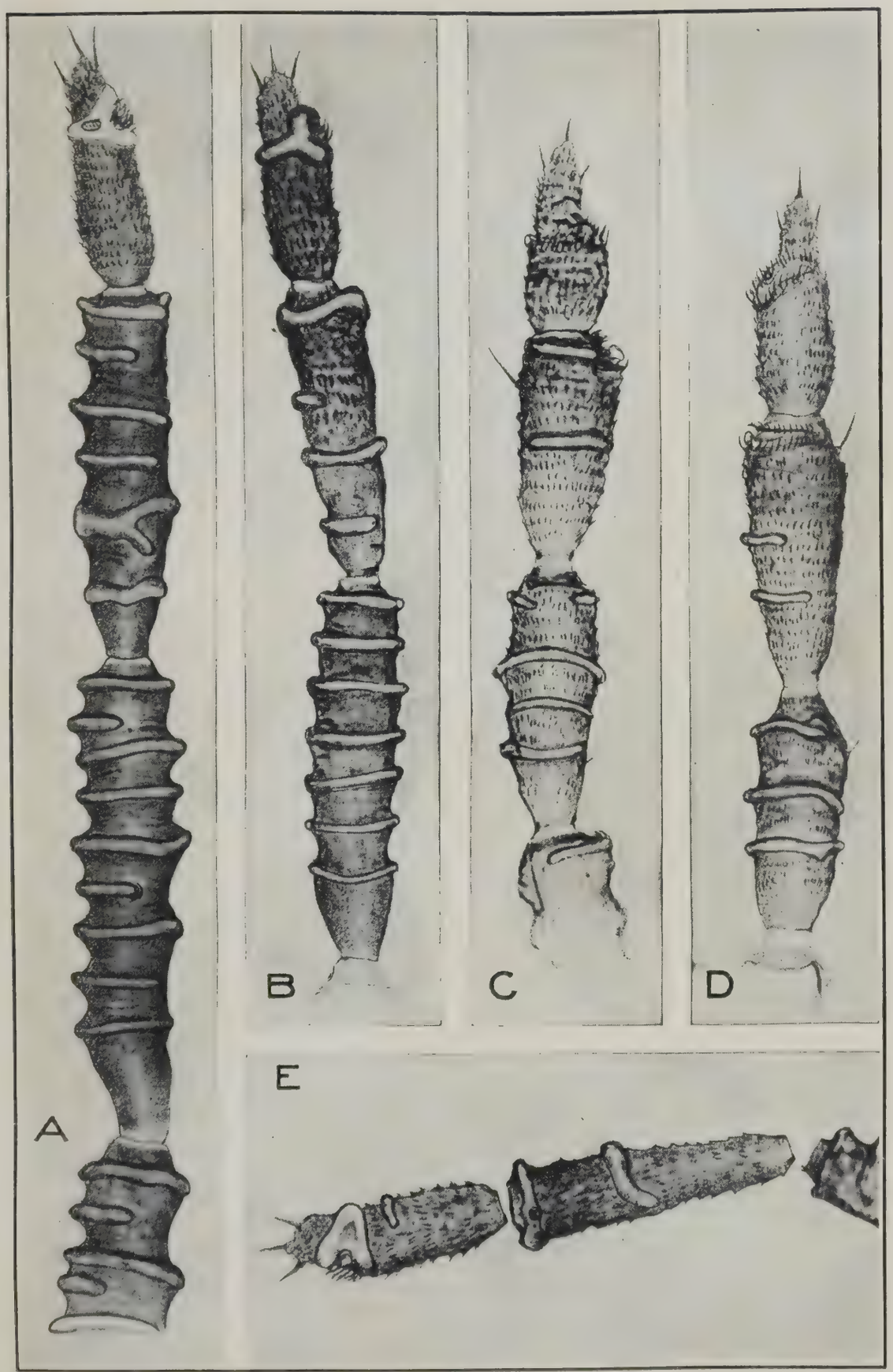
A.—*Eriosoma lanuginosa:* Distal segments of antenna of spring migrant.

B.—*Eriosoma pyricola:* Distal segments of antenna of spring migrant.

C.—*Eriosoma pyricola:* Distal segments of antenna of fall migrant from European pear stock.

D.—*Eriosoma pyricola:* Distal segments of antenna of fall migrant, American material.

E.—*Eriosoma pyricola:* Distal segments of antenna of spring migrant.


A
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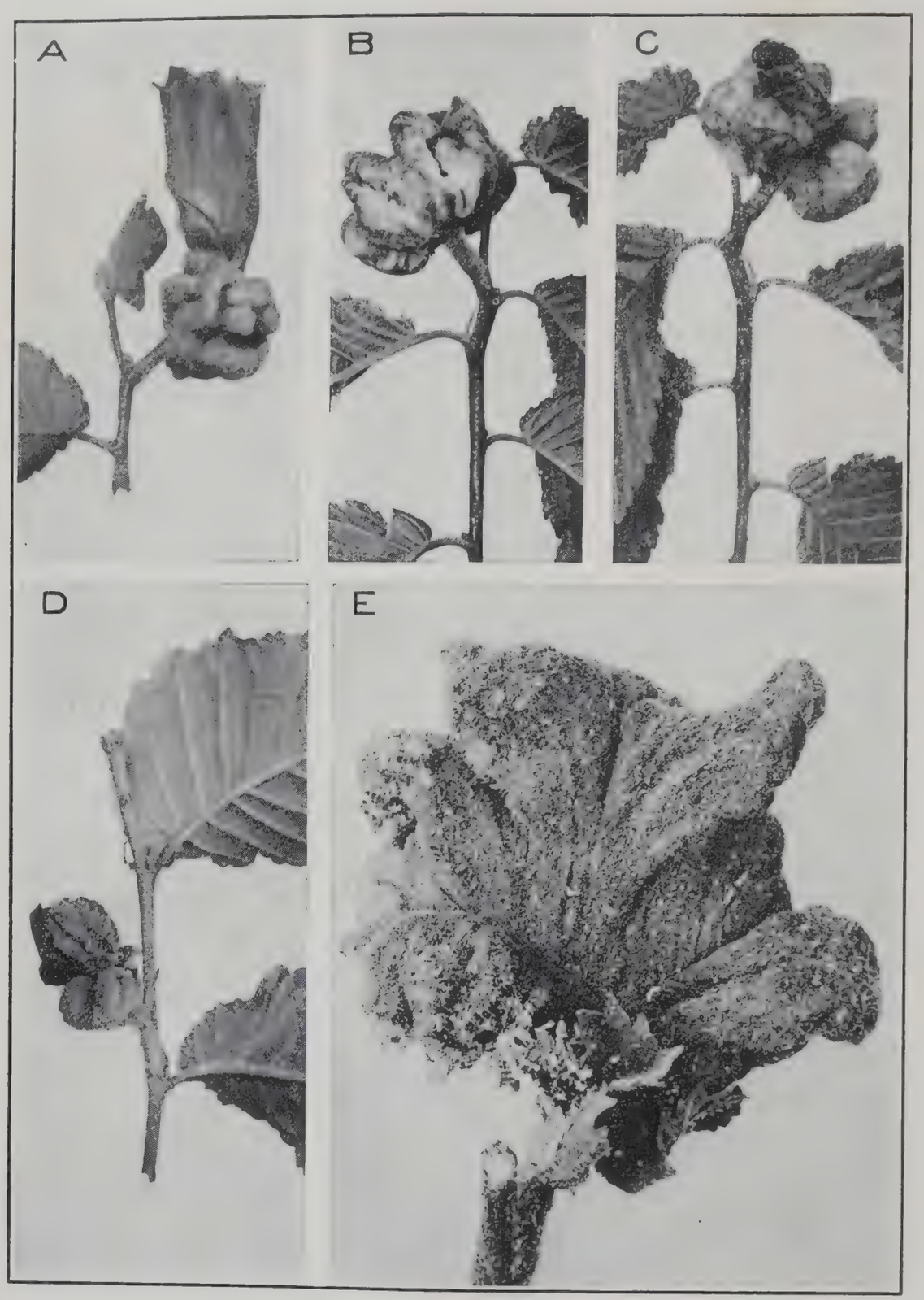
A
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PLATE 10

Eriosoma pyricola:

A, D.—Galls containing fourth-instar stem mothers.
B, C.—Mature galls.
E.—Old gall, slightly enlarged.

MICROORGANISMS AND HEAT PRODUCTION IN SILAGE FERMENTATION

By O. W. Hunter,

Dairy Bacteriologist, Kansas Agricultural Experiment Station

INTRODUCTION

Heat formation is characteristic of silage fermentation. The amount of heat liberated varies as affected by different factors. The average temperature limits of fermenting forage in the center of the silo range between 30° and 40° C. This represents the temperature of normal fermenting silage. There is a marked difference in the degree of heat noted between the fermenting forage at the top and center of the silo. The amount of oxygen present governs to a large extent the amount of heat formed. More oxygen is present in the surface forage than in the center of the silo, which accounts for the higher temperature at the top of the silo.

In European countries silage is referred to as sweet or sour silage, the amount of heat produced governing the type of fermentation. Sweet silage results when the temperature rises to 50° C., while sour silage is formed if the temperature does not exceed 40° C.

PREVIOUS INVESTIGATIONS

Heat production in fermenting forage has never been satisfactorily explained. While it can not be interpreted from previous investigations that this heating results from the major fermentation processes in silage, it seems highly probable. Investigators differ widely regarding the causative agents concerned in silage ripening. Their conclusions may be briefly summarized as follows: Fermentation processes in silage are due to—

(1) Intramolecular respiration of the tissue cells.

(2) Intramolecular respiration of the tissue cells, and microorganisms. The former action is essential, while the latter is of secondary importance.

(3) Microorganisms.

Fry (7)[1] and Babcock and Russell (1, 2, 3) support the first hypothesis, contending that heat production results from the activity of the plant cells. Russell (12), Kayser (10, p. 367–390), and Samarani (13) state that intramolecular respiration is the most important, but that certain bacilli exert a secondary action. Wollny (15, p. 444–460) likewise believes that heat production is caused by the activity of the plant cells, but that the lactic and acetic acids formed are from the action of bacteria.

[1] Reference is made by number to "Literature cited, pp. 82–83.

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Esten and Mason (6) conclude that microorganisms are the predominating factor in silage ripening, but that heat formation is the result of the activity of plant cells. On the other hand, Burrill (4) states that the high temperature attained in his investigations was caused by two or more species of rodlike bacteria to which butyric-acid production could be attributed. Lafar (11, p. 199–203) and Conn (5, p. 112–114) discuss heat production in silage as the result of bacterial action. Griffiths (8) describes several groups of bacteria, important in silage fermentation, but makes no statement regarding silage heating. In a recent article Hunter and Bushnell (9) show that microorganisms are the essential cause of silage ripening. Sherman (14) suggests the probable importance of acid-producing bacilli in the curing of corn silage.

Evidence is sufficient to warrant the assumption that microorganisms are the influential factor in forage fermentation. It is logical to assume, therefore, that the heating of ripening forage is a result of their activities. With this hypothesis in mind the following investigations were planned.

METHOD OF PROCEDURE

Alfalfa, corn, cane, and kafir forage, siloed under laboratory conditions, were used for silage production. The forage was finely cut and packed tightly in 1-quart thermos fruit jars and hermetically sealed. Thermos jars were used in order to prevent as much heat radiation as possible. Care was taken each time to entirely fill the jars before sealing, as such air spaces would afford opportunity for the growth of molds. The heat thus liberated by their activities would offer a source of error in the interpretation of results. In order to bring heat radiation to a minimum, the thermos bottles were kept at a fairly uniform temperature. In a majority of the experiments this temperature ranged between 35° to 37° C. In a few cases, however, they were kept near 20°. The general course of action was the same in each case.

The temperature readings were determined by the use of thermometers and thermo-resistance coils. A type of thermometer was used which allowed the extended mercury end of the thermometer to be inserted to the center of the jar, while the graduations remained above the neck of the bottle. It was graduated to 0.1° C.

The resistance coil consisted of 40 feet of black-enameled magnet wire No. 36, wound around a small-sized spool. A thin coat of paraffin covered the coil in order to insure perfect insulation. The wire leads connecting the coil and resistance box were incased in small glass tubing from the coil to the outside of the thermos jar. This was to avoid breaking the threadlike wires, especially during the filling of the jars. Each was standardized with a thermometer and the resistance readings converted into degrees. The coils also registered to 0.1° C. All thermometers and resistance coils were standardized against each other, and the necessary temperature corrections noted.

The general plan of procedure for determining the relative importance of microorganisms and intramolecular respiration of the plant cells in the heating of siloed forage provided checks of different types on microbial activity. Heat production was observed in—

(*a*) Normal fermenting forage;
(*b*) Forage treated with a weak antiseptic;
(*c*) Forage treated with heat;
(*d*) Heated forage inoculated with bacteria;
(*e*) Cured or dried forage.

Normal fermentation, used as a check, was provided by siloing the untreated forage. When alfalfa was used, 2 to 5 per cent of cane sugar was added to supply an available source of carbohydrate for the ferments.

Forage treated with a weak antiseptic offered favorable conditions for intramolecular respiration of its tissue cells, while the action of the microbial flora was checked. Two to three per cent of chloroform was used for this purpose.

The action of both microorganisms and tissue enzyms was prevented by heating the forage for one to two hours at 100° C. In this way all plant enzyms and the majority of the essential microorganisms were killed. Forage thus made inert was treated with chloroform to check the action of any organisms not killed by the heat and those which entered during the siloing of the heated forage. Such treated forage was used chiefly as a control both for heat production and chemical changes.

Heated forage was also inoculated with a pure culture of the Bulgarian-like organism isolated from silage.

Cured and dried forage, to which the proper amount of moisture had been added to insure conditions for fermentation, was likewise siloed. Owing to the destruction of large quantities of plant enzyms by drying, such forage offered little or no opportunity for tissue activity.

Total acidity determinations were made by the method described by Hunter and Bushnell (9). The results are expressed in terms of lactic acid per gram of dry forage.

EXPERIMENTAL DATA

Only representative records of the different kinds of forage are reported from the large amount accumulated, as all exhibited the same essential characteristics. The temperature readings in each case are plotted as curves. Figures 1 to 10, inclusive, indicate the heat-producing ability of the different kinds of forage. The untreated and inoculated forage all exhibited a marked increase in acid production, while the chloroformed and heated samples exhibited no increase.

Good clean-flavored silage resulted in every instance from the fermentation of the untreated, green, cured, and inoculated forage. The treated

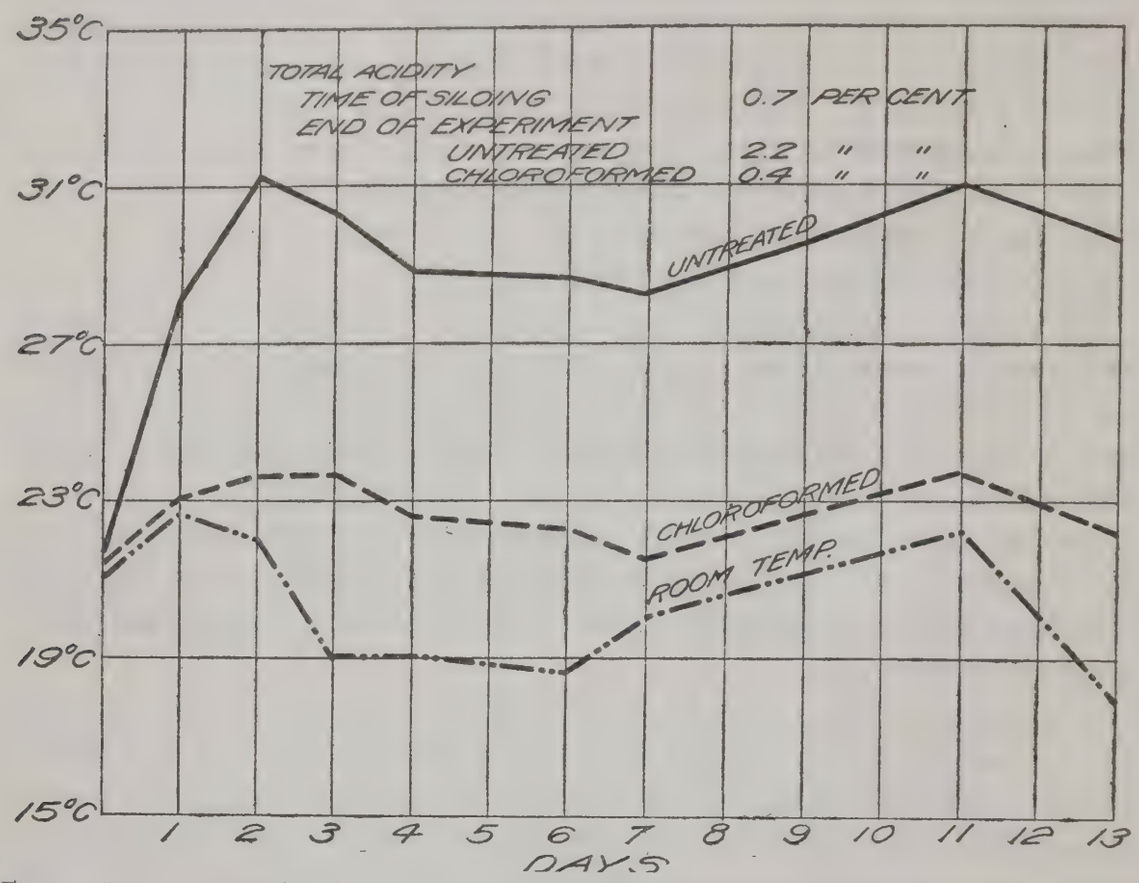

FIG. 1.—Curves representing the heat-producing ability of cured alfalfa, untreated and treated with chloroform.

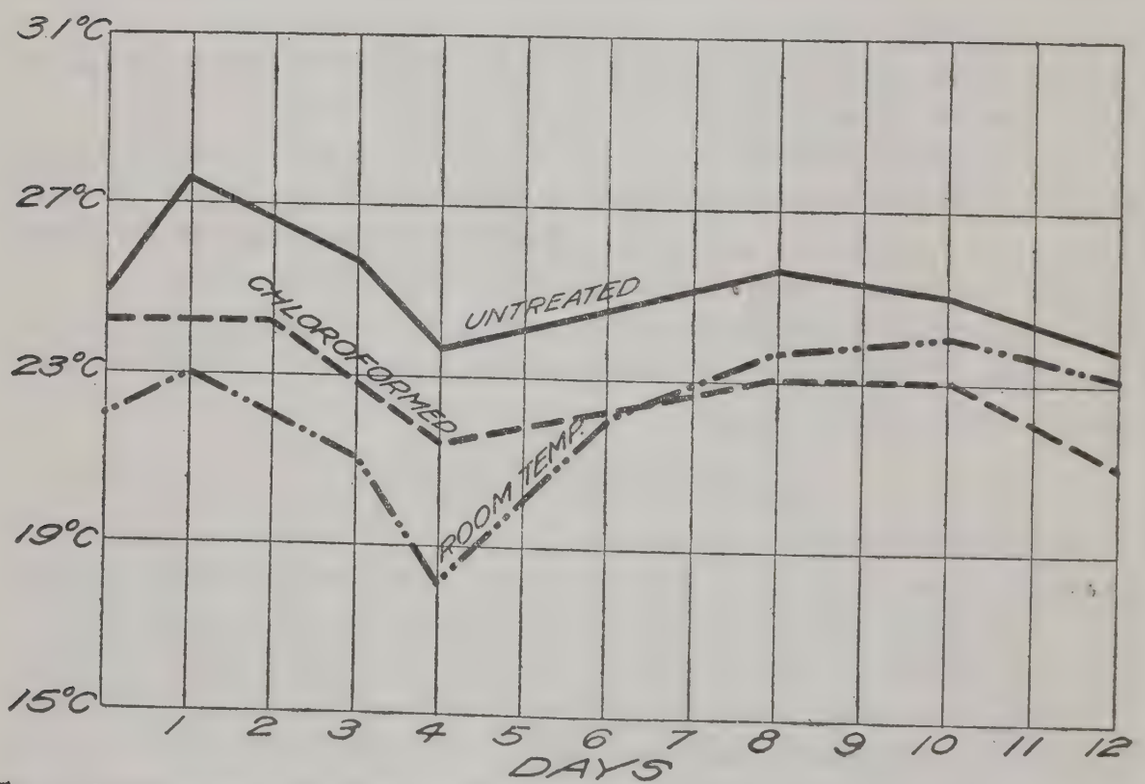

FIG. 2.—Curves representing the heat-producing ability of dry kafir fodder, untreated and treated with chloroform.

forage, that saturated with chloroform and that heated, exhibited no characteristics of silage. The total acidity determinations noted on figures 1, 7, 8, 9, and 10, respectively, indicate the fermentation ability of the various types of forage treated differently.

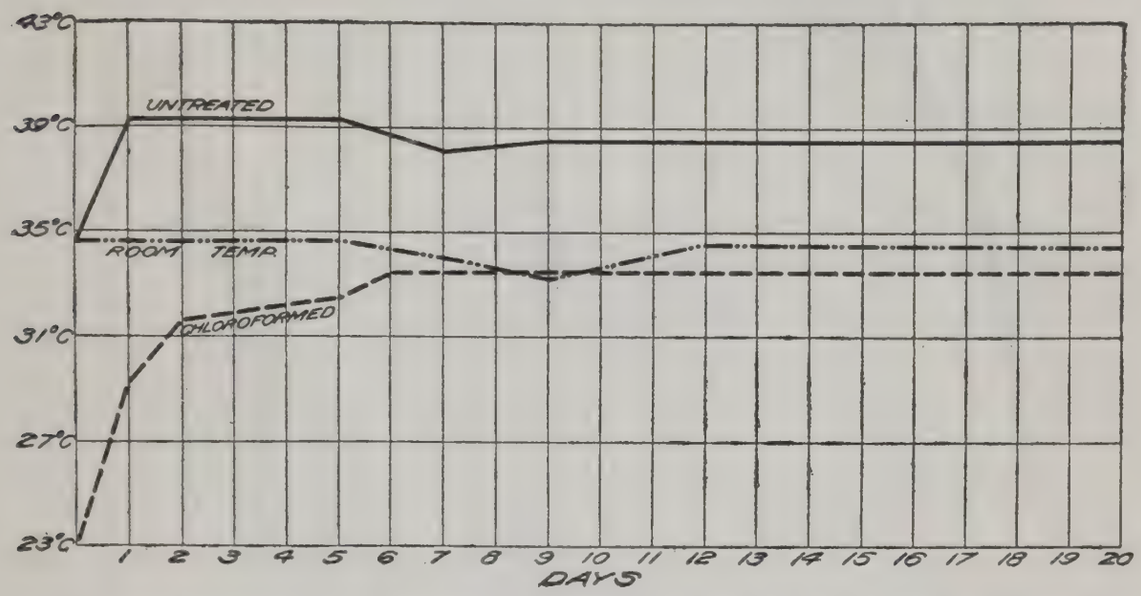

FIG. 3.—Curves representing the heat-producing ability of dry corn fodder, untreated and treated with chloroform and heat, respectively.

Heat production was only observed in the untreated and inoculated forage. The treated samples offered no indications of heating. The differences noted in the comparative amounts of heat production are probably due to the varying amounts of oxygen incorporated in the jars at the time of siloing the forage.

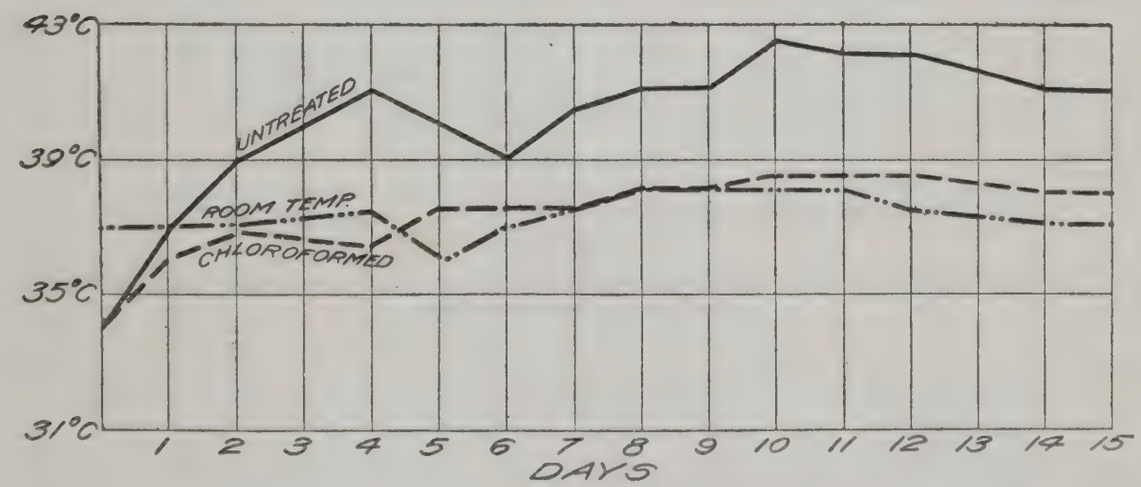

FIG. 4.—Curves representing the heat-producing ability of green cane fodder, untreated and treated with chloroform.

The temperature curve representing the chloroformed forage followed the curve of the heated forage and that of the outside temperature very closely. However, there will be noticed a rapid rise of the treated-forage curves the first few days, which at the first glance might signify heat production. This increase stops at a temperature corresponding

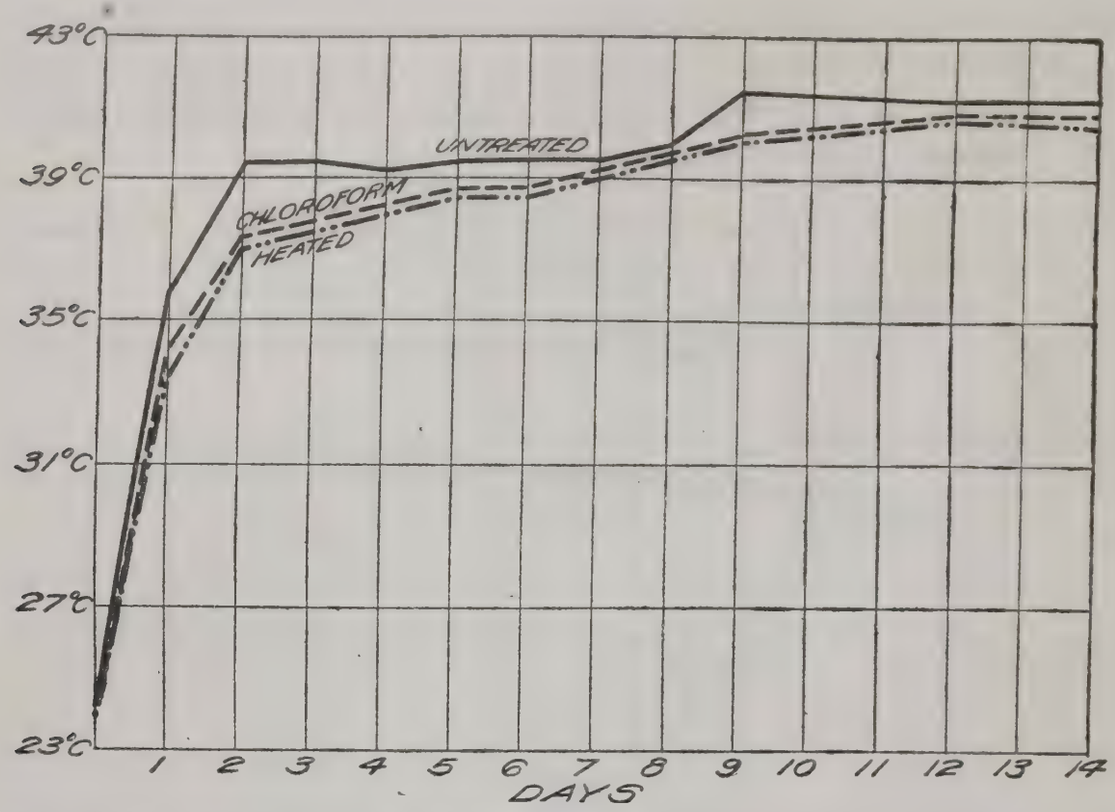

FIG. 5.—Curves representing the heat-producing ability of green alfalfa, untreated and treated with chloroform and heat, respectively.

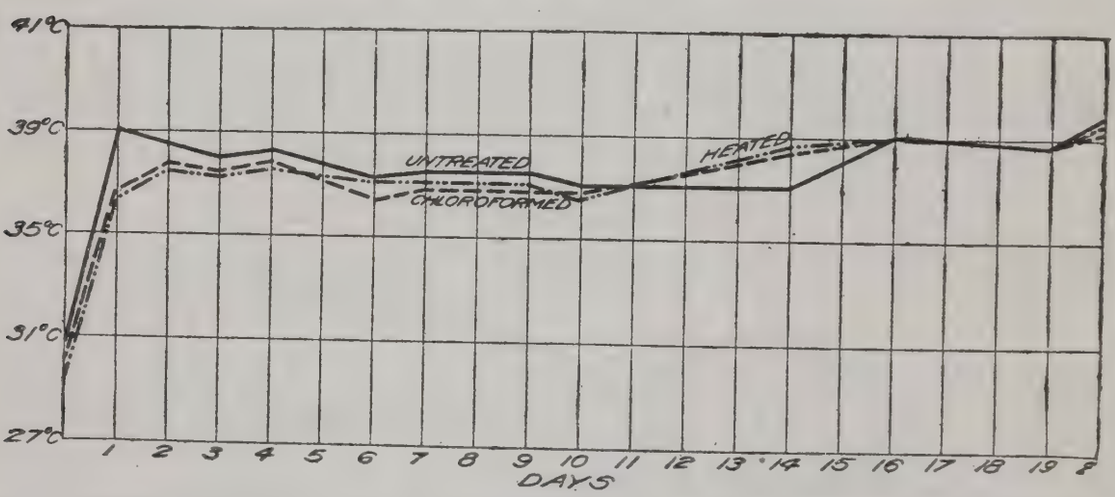

FIG. 6.—Curves representing the heat-producing ability of cured alfalfa, untreated and treated with chloroform and heat, respectively.

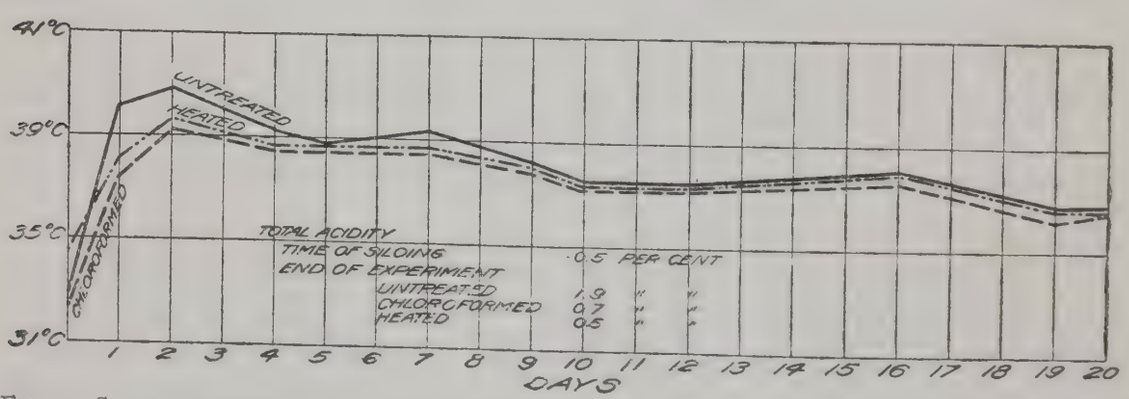

FIG. 7.—Curves representing the heat-producing ability of green alfalfa, untreated and treated with chloroform and heat, respectively.

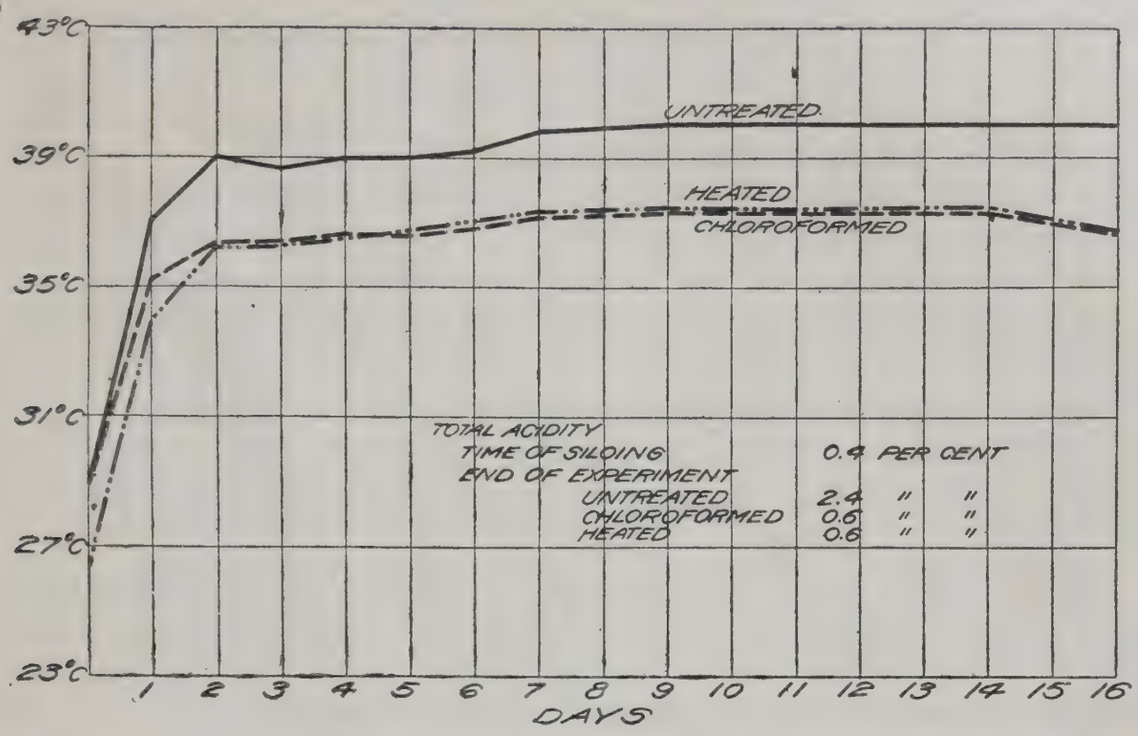

FIG. 8.—Curves representing the heat-producing ability of green corn fodder, untreated and treated with chloroform and heat, respectively.

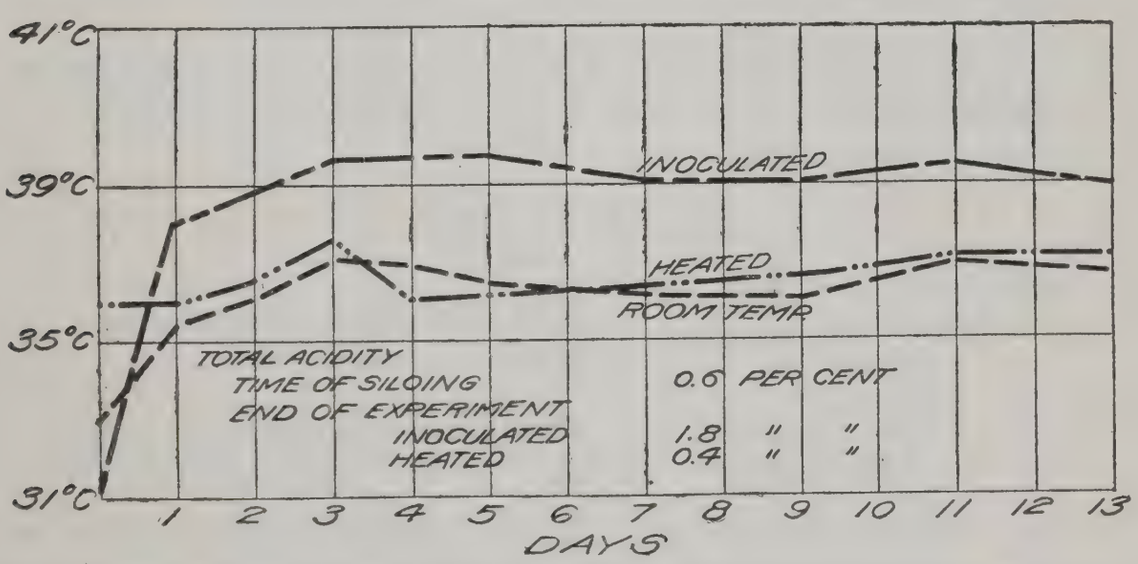

FIG. 9.—Curves representing the heat-producing ability of green kafir inoculated with *Bacterium bulgaricus* and treated with heat.

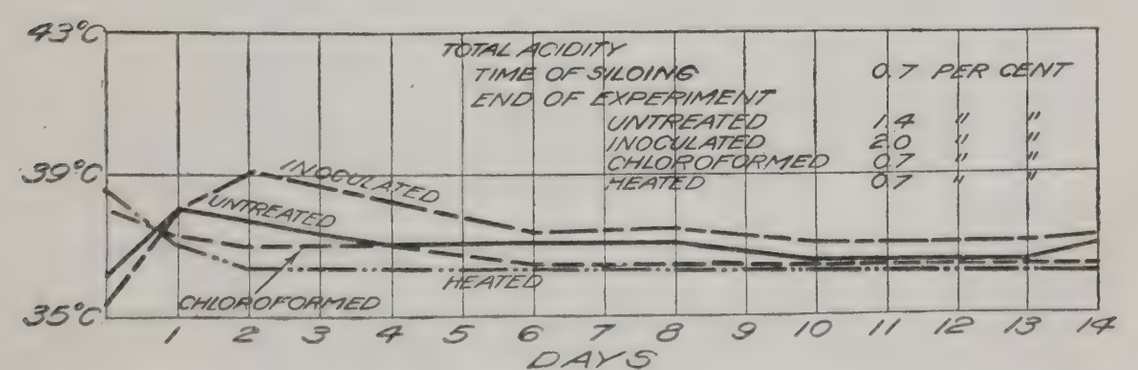

FIG. 10.—Curves representing the heat-producing ability of green kafir, untreated, inoculated, and treated with chloroform and heat, respectively.

with the outside temperature and remains practically the same throughout the experiment. The rise of temperature therefore does not represent heat production in this case, but heat absorption. This is demonstrated by the results in figure 10. Here the temperatures of the untreated and inoculated forage at time of siloing were slightly lower than the temperature of the room (36° to 37° C.) in which the jars were kept, while the temperatures of the treated, chloroformed, and heated were higher. The records in figure 10 indicate a decrease in the temperature readings of both treated samples the first few days, until they corresponded with the temperature outside the jars. The untreated and inoculated samples, however, exhibited heat production, their curves showing a steady rise, exceeding the room temperature and followed by the customary decline.

The fact that dry forage will undergo normal silage fermentation when water is added is significant. Such material can offer no manifestation of cell respiration. However, microorganisms are present and silage is produced. The conclusions are plainly evident.

Temperature curves obtained from the fermentation of dried forage are noted in figures 1, 2, 3, and 6 and are comparable with the fermentation records of green forage.

It is concluded from these investigations that heat production in forage fermentation results from microbial activity and not from intramolecular respiration of the tissue cells.

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ISOLATION OF CYANURIC ACID FROM SOIL

By Louis E. Wise and E. H. Walters, *Biochemists, Soil-Fertility Investigations, Bureau of Plant Industry, United States Department of Agriculture*

In the course of an investigation of an Indiana soil a nitrogenous compound was isolated and shown to be cyanuric acid (Pl. 11). The isolation of this compound was effected in the following manner: Twenty-three kgm. of soil at a time were extracted with about 75 liters of 2 per cent sodium-hydroxid solution at room temperature for 24 hours. The alkaline extract was rendered slightly acid to litmus with sulphuric acid and the acid liquor filtered. The clear acid filtrate was then washed with ether to remove any aldehydes or other soluble acids present, and then treated with an excess of mercuric sulphate in dilute sulphuric acid. The flocculent mercury precipitate was washed by decantation, filtered and washed, suspended in hot water and decomposed with hydrogen sulphid. After the filtration of the mercuric sulphid, the dark-colored filtrate was heated on the steam bath to expel sulphuretted hydrogen, and was then treated with 1 or 2 c. c. of acetic acid. After cooling, this solution was diluted to about 6 liters with water and treated with an excess of a saturated aqueous solution of neutral lead acetate.

The voluminous dark-brown precipitate thus formed was filtered and washed with water. The filtrate was subsequently treated with a large excess of concentrated ammonium hydroxid, and the resulting pale-yellow precipitate was washed by decantation with very dilute ammonia, and finally transferred to a fluted filter paper and washed with water. The moist precipitate was suspended in hot water and decomposed with a rapid stream of hydrogen sulphid.[1] After filtration of the lead sulphid, the straw-colored solution was concentrated to small volume, decolorized with purified boneblack, filtered, evaporated to a brown sirup, and allowed to crystallize. An organic substance then separated, crystallizing in the form of flat plates or small prisms, frequently contaminated with needles of calcium sulphate. The substance was either recrystallized from water or from 50 per cent alcohol, the latter serving to separate it from calcium sulphate. After repeated crystallization from water the compound was obtained in the form of small glassy prisms of varying shapes, which effloresced rapidly when allowed to stand in the air.

The writers were able to establish the identity of the compound obtained from soil with cyanuric acid by carefully comparing its properties with those

[1] A tendency to form colloidal sulphid solutions at this point was sometimes noted. This was overcome by the addition of a few crystals of lead acetate to the solution or by adding small amounts of purified boneblack.

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of synthetic cyanuric acid prepared by heating urea with zinc chlorid by Von Walther's method (12).[1] Both, when subjected to dry heat, decomposed with the formation of a white sublimate and with the evolution of acid vapors having an odor resembling that of glacial acetic acid. Both synthetic cyanuric acid and the compound isolated from soil yielded similar precipitates when treated with mercuric sulphate, ammoniacal lead acetate, and alkaline barium chlorid. A hot aqueous solution of either the compound from soil or synthetic cyanuric acid, when rendered very slightly alkaline with ammonia and subsequently treated with dilute cupric sulphate, and allowed to cool, yielded a copper salt in the form of characteristic rhombic prisms of a beautiful amethyst color (1, p. 1268). This copper salt, which has the formula $Cu(C_3H_2N_3O_3)_2.2NH_3$, may be obtained from as little as 5 mgm. of cyanuric acid. When very small quantities of cyanuric acid are suspected, the test is best carried out in about 1 c. c. of water in the presence of 3 to 4 drops of concentrated ammonia. Under certain conditions not fully understood the test yields a copper salt which crystallizes in the form of fluffy lilac needles, much paler in color than the rhombic form.

To further establish the identity of the substance obtained from soil, a series of comparative analyses were made, using correspondingly small amounts of the soil compound and synthetic cyanuric acid and their respective salts.

On analysis of the compound obtained from soil:

0.0519 gm. of the compound crystallized from water gave 0.01105 gm. of water of hydration;

0.0215 gm. of the anhydrous compound required 0.01252 gm. of sodium hydroxid for neutralization (phenolphthalein indicator) and yielded 0.00697 gm. of nitrogen.

On analysis of the synthetic cyanuric acid:

0.04485 gm. of the acid crystallized from water yielded 0.00945 gm. of water;

0.0354 gm. of anhydrous acid required 0.01084 gm. of sodium hydroxid for neutralization;

0.0600 gm. of anhydrous acid yielded 0.01953 gm. of nitrogen.

	Water (per cent).
Calculated for $C_3H_3N_3O_3.2H_2O$	21.8
Found in compound isolated from Indiana soil	21.3
Found in synthetic cyanuric acid	21.7

	Neutralization equivalent (molecular weight).	Nitrogen (per cent).
Calculated for $C_3H_3N_3O_3$	129.1	32.6
Found in compound from Indiana soil	130.6	32.4
Found in synthetic cyanuric acid	130.7	32.55

Hot aqueous solutions of both the synthetic cyanuric acid and the compound isolated from soil, when treated with silver nitrate and subsequently with ammonium hydroxid, yielded heavy microcrystalline

[1] Numbers in parentheses refer to "Literature cited," p. 90–91.

precipitates. The compounds thus formed were shown to be identical with a previously described silver-ammonium compound having the formula $Ag_2C_3HN_3O_3.2NH_3$ (1, p. 1268), which when analyzed gave the following results:

Preparation from soil compound:
(a) 0.15295 gm. yielded 0.08900 gm. of silver;
(b) 0.14825 gm. yielded 0.08635 gm. of silver.
Preparation from synthetic cyanuric acid:
(c) 0.2615 gm. yielded 0.1510 gm. of silver;
(d) 0.1335 gm. yielded 0.0778 gm. of silver;
(e) 0.1257 gm. yielded 0.0720 gm. of silver.

	Silver (per cent).
Calculated for $Ag_2C_3HN_3O_3.2NH_3$	57.2
Found in the salt derived from soil compound:	
(a)	58.2
(b)	58.2
Found in salt from synthetic cyanuric acid:	
(c)	57.7
(d)	57.5
(e)	57.3

The largest amount of pure cyanuric acid isolated from one of the 23-kgm. lots of the Indiana soil by the above method was about 0.150 gm. Since the isolation must entail some losses, even this should be taken as a minimal value. This quantity of cyanuric acid represents 6.5 p. p. m. and corresponds approximately to 26 pounds per acre-foot, by assuming the weight of an acre-foot to be 4,000,000 pounds.[1]

It should be mentioned in passing that the properties of cyanuric acid are very similar to those of tetracarbonimid as reported by Scholtz (8) and by Schittenhelm and Wiener (7). By accepting the descriptions of tetracarbonimid given by these workers, both compounds when anhydrous have the same percentage composition, and both give similar precipitates when treated with salts of some of the heavy metals. Both compounds when subjected to dry heat decompose with the formation of a white sublimate and acid vapors. On the other hand, cyanuric acid crystallizes from water with two molecules of water of hydration, whereas no mention is made of water of hydration in the case of tetracarbonimid. Furthermore, the neutralization equivalent, which is essentially a molecular-weight determination, should serve to distinguish between cyanuric acid, which has the formula $C_3H_3N_3O_3$, and tetracarbonimid, which has the formula $C_4H_4N_4O_4$, and the silver-ammonium derivative of cyanuric acid described above has a composition different from that of any theoretically possible silver derivative of tetracarbonimid.

[1] The soil contained 0.0744 per cent of total nitrogen. When extracted with a 2 per cent sodium-hydroxid solution, the soil yielded 56 per cent of the total nitrogen to the alkaline solution. On acidification with sulphuric acid and filtration, only 31 per cent of the total nitrogen was found in the acid solution. When treated with mercuric sulphate in dilute sulphuric acid, the acid solution yielded a precipitate which retained approximately 14 per cent of the nitrogen originally present in the soil. The cyanuric acid isolated corresponds to about 0.30 per cent of the total nitrogen in the soil.

The close similarity in the behavior of tetracarbonimid and cyanuric acid may make the identification of either a difficult matter; and, if the amounts of substance isolated from soil are too small for analysis, it may be impossible to distinguish between the two. In a previous paper (10) from this laboratory the isolation of tetracarbonimid from a number of soils was reported. The compound isolated from one of these soils (a loam soil from the grounds of the Department of Agriculture) was obtained in a quantity too small for analysis. Since then it has been possible to obtain more of this compound from the soil then examined, and the supposed tetracarbonimid has been shown to be cyanuric acid. The analytical data relating to this compound are given below:

0.0564 gm. of the compound required 0.01728 gm. of sodium hydroxid for neutralization and yielded 0.01811 gm. of nitrogen.

	Neutralization equivalent (molecular weight).	Nitrogen (per cent).
Calculated for $C_3H_3N_3O_3$	129.1	32.6
Found	130.6	32.1

The compound from this lawn soil also yielded a rhombic amethyst-colored copper compound similar in all respects to the compound obtained from synthetic cyanuric acid. On analysis:

0.02970 gm. of the copper compound prepared from the substance obtained from this soil gave 0.00660 gm. of cupric oxid.

0.015995 [1] gm. of the copper compound obtained from synthetic cyanuric acid gave 0.003535 gm. of cupric oxid.

	Copper (per cent).
Calculated for $Cu(C_3H_2N_3O_3)_2.2NH_3$	17.96
Found in the copper salt prepared from the compound obtained from the lawn soil	17.75
Found in the copper salt prepared from synthetic cyanuric acid.	17.65

The amount of cyanuric acid isolated from 23 kgm. of lawn soil was approximately 110 mgm. This amount corresponds to about 19.5 pounds per acre-foot.

Cyanuric acid was also isolated from three other soils. A Maine soil yielded about 0.165 gm. of cyanuric acid (sample a) from 46 kgm., a Florida soil yielded approximately 0.040 gm. of cyanuric acid (sample b) from 23 kgm., and a Texas soil yielded about 0.040 gm. of cyanuric acid (sample c) from 46 kgm.

The following analytical data were obtained:

0.059 gm. of crystallized sample (a) gave 0.0124 gm. of water;

0.04785 gm. of anhydrous sample (a) required 0.01458 gm. of sodium hydroxid for neutralization and yielded 0.01575 gm. of nitrogen;

0.0328 gm. of anhydrous sample (b) required 0.010 gm. of sodium hydroxid for neutralization and yielded 0.01060 gm. of nitrogen;

0.0382 gm. of crystallized sample (c) gave 0.0087 gm. of water;

[1] These weighings were performed on an ordinary chemical balance by the method of interpolation as described in text books on physical measurements.

0.0295 gm. of anhydrous sample (c) required 0.009 gm. of sodium hydroxid for neutralization and yielded 0.00969 gm. of nitrogen;

0.03076 gm. of the copper compound derived from sample (a) yielded 0.006765 gm. of cupric oxid.

	Water (per cent).
Calculated for $C_3H_3N_3O_3.2H_2O$	21.8
Found in sample (a)	21.0
Found in sample (c)	22.8

	Neutralization equivalent.	Nitrogen (per cent).
Calculated for $C_3H_3N_3O_3$	129.1	32.6
Found in sample (a)	131.3	32.9
Found in sample (b)	128.6	32.3
Found in sample (c)	131.1	32.8

	Copper (per cent).
Calculated for Cu $(C_3H_2N_3O_3)_2.2NH_3$	17.96
Found in copper compound derived from sample (a)	17.6

The soils from which cyanuric acid has been isolated are of widely different origin and type, and it may be expected that the compound or its precursor has a rather wide distribution. The Indiana soil which yielded cyanuric acid belongs to a type which is described (6) as Scottsburg silt loam, light to very light ashy-gray in color, having an average depth of 8 to 10 inches. Fine and very fine sand mixed with the silt gives the soil many of the characteristics of a fine sandy loam. As a type the soil is fairly well drained. The Maine soil used in our work is Caribou loam (13), devoted to potato culture. The soil is underlain at a depth ranging from a few inches to several feet by shale. The drainage is good. The Florida soil above mentioned is chiefly quartz sand and contains very little organic matter. It is devoted to orange culture. The Texas soil, Susquehanna fine sandy loam, is the same soil from which α-crotonic acid has been isolated (11).

Cyanuric acid, which yields two series of isomeric esters (3, p. 181) and mercury salts (4), may be represented by the tautomeric formulas:

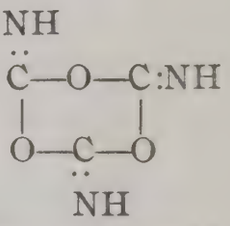
Lactam form. Lactim form.

It is a polymer of cyanic acid, OC:NH.

Cyanuric acid was probably first prepared by Scheele by heating uric acid (2). In 1830 it was synthesized by Serrulas (2) by treating solid cyanogen chlorid with water, and the following year Wöhler prepared it

(2) by heating urea. Wöhler's synthesis of cyanuric acid has been recently modified by Von Walther (12), whose method has been outlined above. Besides these classic methods of preparation, the literature is replete with descriptions of the synthesis of this compound, and mention is frequently made of the occurrence of cyanuric acid as a by-product in reactions involving compounds having the $\diagdown C{:}NH$ or $\diagdown C.NH_2$ groups.

Cyanuric acid is also formed from its isomer cyamelid,



on prolonged digestion with cold dilute alkali (5). This reaction should be emphasized, since it suggests that cyamelid, if present in the soil, would be converted into cyanuric acid by the method here followed. The isolation of cyanuric acid might even be taken as indicative of the presence of cyamelid, since an alkaline extraction would convert cyamelid into cyanuric acid. Cyamelid may therefore be the precursor of the cyanuric acid isolated in our experiments. Cyamelid is insoluble in all the ordinary organic solvents, and the solvents in which it is soluble (alkali and concentrated acid) convert it into cyanuric acid. It seems impossible therefore to determine whether or not cyamelid is a soil constituent and the mother substance of the cyanuric acid isolated.

Although so frequently referred to in the literature, cyanuric acid has apparently never been previously isolated from a natural source. The above methods of obtaining cyanuric acid suggest the possibility of its formation by the decomposition of nucleoprotein or purin bases, some of which have been previously isolated from soil (9). It is also conceivable that the source of cyanuric acid is urea.

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PLATE 11

Cyanuric acid isolated from Indiana soil. × 120.

FAMILY PERFORMANCE AS A BASIS FOR SELECTION IN SHEEP

By E. G. RITZMAN, *Animal Husbandman, New Hampshire Agricultural Experiment Station*, and C. B. DAVENPORT, *Station for Experimental Evolution, Carnegie Institution of Washington*

Two contrasted methods of selecting mates are in current use. The commonest is that of picking out the best individuals or those that exhibit the traits which are desired in the offspring. This method depends on the principle that the somatic traits of the parent are the best index of its germinal determiners; so that in selecting somatically we are at the same time selecting gametically. This principle is, however, false in so far as the soma is usually a very inadequate index of the germ plasm. In animals that are heterozygous in any trait the germ cells are of two kinds in respect to that trait: (1) those carrying determiners for the trait and (2) those for its absence, or for its allelomorphic trait. Practically it has been found by many breeders of animals and plants that progress is made slowly or not at all by this process.

The other method of selecting mates recognizes the principle that the individual's somatic traits constitute a partial and imperfect index to its germ plasm. A better insight into that germ plasm is gained by considering the traits shown by as many close relatives as possible. Naturally the qualities of the proposed mates are considered, but only as members of their families.

The foregoing principles have been applied in the sheep-breeding experiments at the New Hampshire Experiment Station. The aim of these experiments is to produce a race of sheep that will combine good qualities of conformation, size, and wool. As criteria of these three points we used the following quantities and assigned to each the factor or weight indicated:

	Weight.
SIZE	
Body weight (pounds)	5
Height at shoulder	5
Chest circumference	5
Loin width	5
Hindleg circumference	5
Total size	25
WOOL	
Weight of fleece	10
Length of staple	10
Diameter of fiber	10
Crimp of wool	10
Total wool	40

	Weight.
CONFORMATION	
Ratio, head width: length	3
Ratio, neck length: circumference	2
Ratio, foreleg length: trunk length	10
Ratio, chest width: depth	5
Ratio, chest width: trunk length	5
Ratio, loin width: trunk length	5
Ratio, croup length: trunk length	5
Total	35

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The method of selecting by family performance is a natural corollary of the principle that offspring do not "inherit from their parents" but that offspring are derived from some of the same kind of germinal stuff as that from which those parents and their brothers and sisters were derived. And the best knowledge of the varied qualities of the germ plasm is obtained by a comprehensive view of its performance in a number of closely related, fully developed somas. The studies of a score of geneticists (among whom it may not be invidious to mention Pearl, working with the fecundity of poultry) are in agreement upon this point.

Since most of the ewe lambs, but, on the other hand, only a very few ram lambs, are preserved as breeders, the selection of males is the more rigorous. We may illustrate the general method of selection by an example. In the 1916 selection the available ram lambs belonged to 12 "families." A "family" comprised brothers and sisters and the two parents. In selecting the trait "body weight" the average weight of all the members of each family group at a fixed age is calculated. The family having the highest average weight is graded 1; the next highest average is 2; and so on. If the average is the same in two families, they receive the same grading rank; thus, in one selection two males grade No. 4 in body weight and four grade No. 2 in shoulder height. Naturally, one family will grade high in body weight, but low in weight of fleece and perhaps will be medium in ratio of head width to head length. The rank of every family with respect to every quantitative trait is thus determined; the rank is multiplied by its appropriate weight factor as in ordinary scoring. The family which gives the lowest sum of products grades highest, and the best ram from that family (or the better if there be two) is ordinarily chosen. However, if the individual belonging to the "best" family is sickly or has any physiological quality that would interfere with its success as a breeder, the male from the next higher family may be preferred—that is, selection is made primarily on the basis of family performance, but the somatic insufficiency of the individual is permitted to veto the choice based on amily alone. To facilitate such veto, the individual males from which selection is to be made are graded on the basis of their quantitative traits. It is practically found that the best individuals usually come from the families that stand high in the scale. If the representative of the best family should be a ram grading at the bottom of the scale individually, he would probably be rejected and the representative of the second-best family selected. But practically, as stated, the question of relative weight to be given to the individual (as contrasted with family) does not cause much hesitation so long as the principle of selecting permanently on the basis of family is kept in view.

To illustrate the foregoing the procedure in a particular case is given in Tables I and II.

TABLE I.—*Grading of families from which breeding rams are to be selected* [a]

Family No.	1	2	3	4	5	6	7	8	9	10	11	12
Size:												
Body weight, pounds	11	5	7	2	4	8	3	9	6	10	4	1
Height, shoulder	7	1	8	4	2	2	2	6	5	7	3	2
Chest circumference	11	5	8	1	9	7	2	10	4	12	6	3
Loin width	6	3	6	5	8	8	6	7	4	7	1	2
Hindleg circumference	6	8	9	4	7	2	4	3	5	10	4	1
Size totals × 5	205	110	190	80	150	135	85	175	120	230	90	45
Ratio:												
Head width: Head length (3)	6	12	12	6	18	9	3	9	6	12	15	9
Neck length: Neck circumference (2)	16	2	10	8	2	4	8	2	8	12	6	14
Foreleg length: Trunk length (10)	50	20	40	70	90	60	10	80	70	80	30	70
Chest width: Chest depth (5)	20	10	20	5	20	25	15	35	15	30	10	5
Chest width: Trunk length (5)	15	10	15	10	10	10	15	20	10	15	10	5
Loin width: Trunk length (5)	15	15	15	15	20	20	20	15	15	15	10	5
Croup length: Trunk length (5)	30	20	20	15	20	5	30	15	10	25	15	15
Ratio totals	152	89	132	129	180	133	101	176	134	189	96	123
Wool:												
Weight of fleece	11	6	10	2	3	1	2	7	4	9	5	8
Length of staple	9	11	10	1	12	8	7	3	5	4	6	2
Fineness of fiber	4	3	3	3	1	2	1	2	3	2	3	1
Crimp	3	1	8	7	6	5	4	3	4	8	3	2
Wool totals × 10	270	210	310	130	220	160	140	150	160	230	170	130
Grand total	629	409	632	339	550	528	326	501	414	649	356	298
Order of excellence	10	5	11	3	9	8	2	7	6	12	4	1

[a] The number in parenthesis under ratio indicates weight factor by which the grade is multiplied to give product in columns 1 to 12.

Table I shows how families are graded. In this case the first family in order of excellence is No. 12, in which the ram is No. 32. Table II shows that this ram is one of the first two in order of individual excellence. It was accordingly selected as our best sire. The second-best family is No. 7. The ram in this family stands seventh in order of excellence; it was our second choice. The third-best family is No. 4; the ram in this family ranks as the third-best individual; it was chosen as our third-best ram, and so on. The poorest family is No. 10, and the ram from that family is the poorest individual. Ram 64 (family 5) shared first rank with ram 32, but it was not used, despite its very heavy fleece and fine fiber, because the family record for weight of fleece was not extragood, and conformation is very poor.

TABLE II.—*Grading of rams for individual excellence* [a]

Family No.	1	2	3	4	5	6	7	8	9	9	10	11	12
Number of ram	45	28	49	51	64	55	56	58	30	59	60	26	32
Size:													
Body weight, pounds	12	5	11	6	3	8	4	9	2	7	10	4	1
Height, shoulder	10	3	8	6	5	6	4	9	1	9	7	5	2
Chest circumference	13	6	10	7	2	8	3	11	1	9	12	5	4
Loin width	12	3	5	8	4	10	6	11	2	7	9	3	1
Hindleg circumference	8	5	11	7	6	9	2	4	3	10	12	13	1
Size total × 5	275	110	225	170	100	205	95	220	45	210	250	150	45
Ratios:													
Head width: Head length (3)	12	9	15	6	21	12	3	9	18	6	12	24	24
Neck length: Neck circumference (2)	2	22	6	8	20	10	16	18	24	6	4	14	12
Foreleg length: Trunk length (10)	60	80	20	30	10	40	70	40	50	20	60	40	30
Chest width: Chest depth (5)	15	20	25	25	20	30	5	35	15	20	25	25	10
Chest width: trunk length (5)	15	20	10	25	20	15	15	25	10	10	30	25	5
Loin width: Trunk length (5)	30	20	10	25	15	20	25	25	15	15	25	15	5
Croup length: Trunk length (5)	40	35	10	30	20	20	30	25	10	15	10	10	5
Ratio total	174	206	96	149	156	147	234	177	142	92	166	153	91
Wool:													
Weight of fleece	12	10	11	2	1	3	6	8	7	4	10	5	9
Length of staple	2	12	6	1	8	13	7	5	10	4	9	3	11
Fineness of fiber	2	6	5	3	4	1	6	5	7	3	3	6	6
Crimp	1	2	5	6	4	3	3	2	5	3	7	4	3
Wool total × 10	170	300	270	120	170	200	220	200	290	140	290	180	290
Grand total	619	616	591	439	426	552	549	597	477	442	706	483	426
Order of excellence	12	11	9	3	2	8	7	10	5	4	13	6	1

[a] The number in parenthesis under ratio indicates weight factor by which the grade is multiplied to give product in columns 1 to 12.

The system deals not only with relative values. The natural supplement is the real or imaginary "ideal" combining in actual (not relative) degree the traits of the model which we are trying to produce in making our selections. This principle is, of course, also fully recognized by live-stock judges and breeders' associations. With the "ideal" in mind it becomes possible to form a proper estimate of the somatic value of an individual or of a family composite.

In adopting this method of selection an ideal was sought that would combine the desirable traits from each of the two breeds used in our

experiments, Southdown and Rambouillet.[1] These were size and conformation of the former and wool characters of the latter, but intermediateness in thickness of fiber and length of not less than 3 inches. As the Southdown ram 28169 represents an exceptionally desirable type, combined with unusual size for the breed, his measurements were adopted to represent the "ideal" as regards conformation and size.

The ideal score, then, is shown in Table III.

TABLE III.—*The ideal score for size and conformation of rams*

Measures.[a]			Ratios.	
Weight	pounds	200	Head width / Head length	0.68
Height, shoulder	mm	635		
Head length	mm	200		
Head width	mm	135	Neck length / Neck circumference	.60
Neck length	mm	285		
Neck circumference	mm	475	Foreleg length / Trunk length	.59
Trunk length	mm	645		
Chest circumference	mm	1,100	Chest width / Chest depth	.86
Chest depth	mm	350		
Chest width	mm	300	Chest width / Trunk length	.46
Loin width	mm	200		
Croup length	mm	180	Loin width / Trunk length	.31
Foreleg length	mm	380		
Hindleg length	mm	455	Croup length / Trunk length	.28
Hindleg circumference	mm	485		

[a] These measurements can all be taken with a simple and inexpensive caliper or with a string.

The results of this method of selection can not yet be given in detail, as the experiment is still in progress. The uniformity of the progeny and the high quality already shown by the earlier generations give us every reason for confidence that this method of selecting by family performance in place of individual traits is well worth the extra trouble it entails, if, indeed, it is not indispensable.

[1] An "ideal" score may, of course, be subject to change. It must be progressive, as animal breeding is progressive.

A NEEDLE BLIGHT OF DOUGLAS FIR

By JAMES R. WEIR,

Forest Pathologist, Office of Investigations in Forest Pathology, Bureau of Plant Industry, United States Department of Agriculture

The fungus described in this paper has been under the writer's observation since 1911. The damage resulting from its activities in forest and nursery since the date of its first discovery has been so great that some mention should be made of it at this time. During the past season (1916) the fungus has been so aggressive in its attacks that strenuous efforts must be made to prevent serious injury to Douglas fir [*Pseudotsuga taxifolia* (Lam.) Britton] in the nurseries. The wide distribution of this fungus in the forests of the Northwest and its destructive effects on young Douglas fir, from seedlings to the 30-year class, have recently become of great concern to foresters. Much material and many letters regarding the disease have been received at the Missoula laboratory from all parts of the Northwest. It is highly instructive to quote from a few of these communications. Mr. J. B. Seely, Forest Supervisor of the Helena National Forest, writes, under date of April 23, 1915:

> The affected timber, *Pseudotsuga taxifolia*, covers an area of several hundred acres in secs. 7, 8, and 9, T. 5 N., R. 5 E., having a northern exposure at an altitude of about 6,500 feet. The affected area is within a pure stand of Douglas fir, and has not increased in any way since first observed nearly two years ago.

Through more recent reports and through observations in this region by the writer, other infected areas have been discovered. Mr. J. B. Lafferty, Forest Supervisor of the Weiser National Forest, Idaho, under date of February 16, 1915, writes:

> Assistant Forest Ranger E. E. McGinnes, in whose district the disease seems to be most prevalent, reports that seedlings and saplings that were badly affected in 1913 died from the effect during the past season; and that the disease is apparently spreading and attacking larger trees.

Mr. John A. Pearson, Forest Supervisor of the Salmon National Forest, Idaho, under date of June 7, 1915, writes that:

> On December last the disease was first noticed on a ridge on the west side of the North Fork of the Salmon River. Since then it has spread to the east side of the river and down both sides for a distance of about 3 miles. The yellow pine does not seem to be affected in any way and very few of the older fir (*Pseudotsuga taxifolia*). Trees from 2 to 20 feet in height seem to suffer most. Some of the trees are nearly bare of foliage, and while it is too early yet to determine whether or not they will die, it seems probable that they will. Infection occurs in spots of from 3 to 20 acres in area, or wherever the reproduction is the best.

A great deal of material was examined from the regions not visited by the writer.

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The needles of Douglas fir infected with this fungus in early winter develop spots of a slightly yellow color on the under surface, principally at their tips. Each spot represents a single infection and may be very sharply separated from the unaltered green of the uninfected parts of the leaf. Somewhat later the tissues of the leaf on the upper surface directly opposite also turn yellow. By early spring (April and May) these spots have changed to a yellowish brown, and since the uninfected parts of the leaf may remain wholly green, merging into a light-yellow zone next to the area of infection, a peculiar mottled appearance results. About the first of June the needles have assumed, in the case of severe infection, a more uniform brown color, and the entire stand looks as if it had suffered from a severe frost. On the under surface, on either side of the middle nerve of the needle, the spots, now dark brown, begin to round up as small cushions. About the middle of June the epidermis covering these brown areas ruptures with an irregular slit exposing the brownish disk (fig. 1). In cases of severe infection the needles have a very striking appearance (Pl. 12, *A*). At this stage asci in all degrees of development are present (fig. 2). Very frequently, if the tree has been much suppressed by the destruction of its needles through several seasons, mature spores are abundant. By July 1 the asci (fig. 3) are fully mature, and sporulation is active. The liberation of the spores is very greatly promoted by the force of wind and rain on the leaf. When the spores fall on the young needles of the season, which at this period are rapidly growing, it is observed that infection takes places shortly afterwards, provided sufficient moisture is present.

FIG. 1.—Needle of Douglas fir infected with the needle-blight fungus, showing various forms of apothecia and the manner of their rupture.

Snow does not promote the spread of the fungus, as shown by the fact that the needles of the branches of the crown are as badly infected as those lower down. If a wet summer follows the infection, the needles begin to show signs of being diseased before October; otherwise they will remain apparently healthy until December.

The infected needles fall at all seasons of the year, owing to the fact that a portion of them are not as seriously infected as others and may remain on the tree for an indefinite period. A slight jar is often sufficient to cause the needles to fall in a shower. Those that remain longest on the tree after infection produce the apothecia in the spring. In case of a very severe infection, owing to the rapid drying out of the twigs, the needles may remain indefinitely attached, the apothecia becoming black and shrunken. Trees which have been subject to the ravages of the fungus

for several seasons are almost entirely defoliated and either die or merely exist for an indefinite period without making any perceptible growth (Pl. 12, *B*).

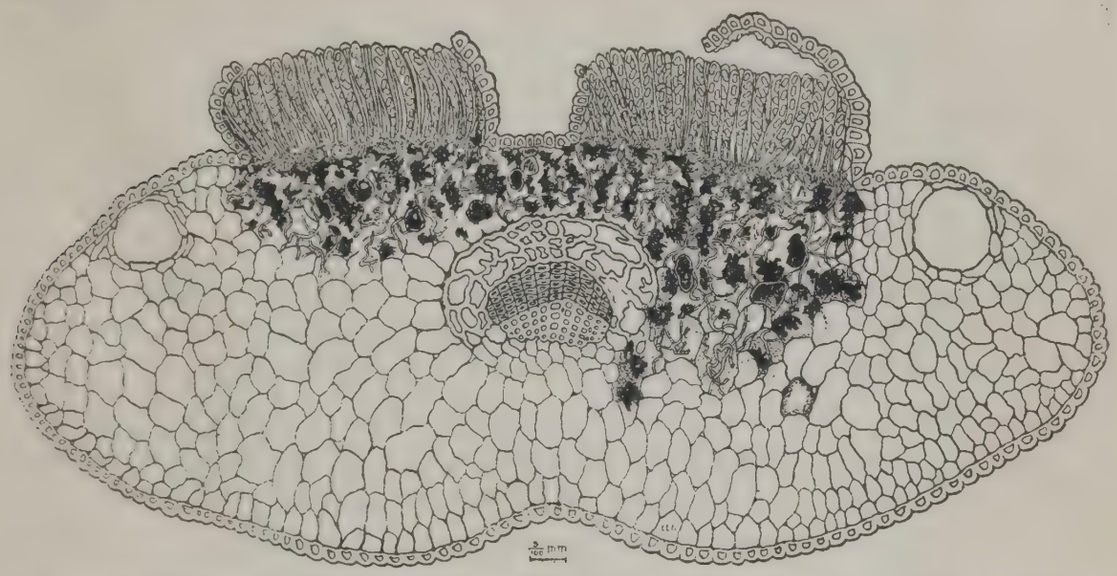

FIG. 2.—Cross section through the middle of two apothecia of the needle-blight fungus, showing the arrangement of the asci and spores, the diseased area of the needle, disorganized cells, and mycelium.

The greatest damage is done in close, pure stands. Since this type of stand is prevalent in many parts of Montana, Idaho, and Washington, the fungus becomes a serious menace to the forest. Repeated observations show that when the fungus becomes once established in dense, even-aged reproduction, none of the ordinary conditions of climate which have been known to arrest other needle diseases seem to prevail against it. It is significant, however, that those trees of the older age classes which are in a close stand and which have escaped the general canopy are, in most cases, free from the disease. Douglas fir in mixed stands is not so frequently attacked.

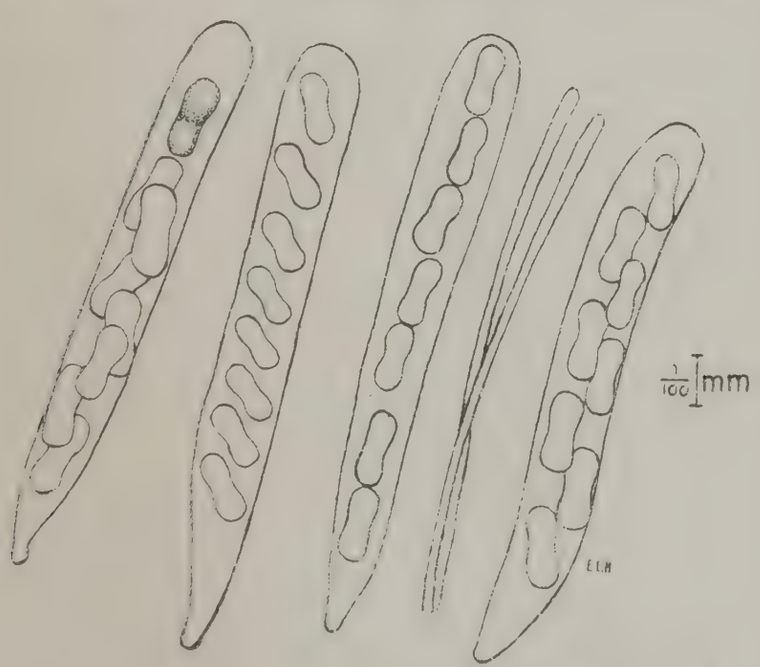

FIG. 3.—Asci with mature spores of the needle-blight fungus on Douglas fir.

The parasitic nature of the fungus is shown by its ability to attack the young needles of the most vigorously growing trees; also by the fact that it does not attack any more rapidly the needles of trees suppressed by mistletoe, root fungi, or insects.

The first evidence that the fungus might cause a serious disease of seedlings in the forest nursery was obtained from a study of all age classes on a south slope in the Bitterroot National Forest, near Missoula, Mont. Practically all reproduction up to 25 or 30 years of age was heavily infected, and in numerous instances the seedlings were dead.

On June 17, 1915, during a visit to the Forest Service nursery at Boulder, Mont. (Helena National Forest), the writer discovered the fungus in the seed beds of 2- to 4-year-old Douglas fir stock. These beds were carefully examined and not one seedling was found to be entirely free from the disease. In most cases all the needles of the previous seasons bore the apothecia of the fungus which in a number of instances was associated with *Botrytis cinerea* Pers. (*B. douglasii* Tubeuf). The latter attacks and kills the young shoots of the season, and is very prevalent in the forests and nurseries of the Northwest.[1] In the denser portions of the beds the fungus was likewise aided in its destructive work by an unusual infestation of what the writer took to be *Chermes cooleyi* Gillette. At the time of the visit the seedlings in the transplant beds were not seriously infected. The pure stands of Douglas fir in the same canyon where the nursery is located were severely infected and exhibited the most serious injury so far observed anywhere in the Northwest. From the observation of field plantings, it is known that Douglas fir seedlings previously infected in the nursery by the fungus under discussion succumb in a very short time. A dozen 3-year-old seedlings infected with the disease were brought from the Boulder nursery and carefully transplanted in the greenhouse at Missoula on December 23, 1914. Before April 26, 1915, the infected needles fell off and the seedlings died. Uninfected seedlings from the same source transplanted at the same time remained healthy. The need of planting healthy seedlings in the field is very apparent. Methods have been devised and are now in practice by which it is hoped this may be realized. A solution of soap and Bordeaux mixture (4–4–50) followed by the standard kerosene emulsion has given indication of being a successful remedy for the fungus. The application of the kerosene emulsion is found to be successful against *Chermes cooleyi*, which greatly aids the destructiveness of the fungus.

The systematic position of the fungus is difficult to determine. Specimens have been referred by the writer both to the Phacidiaceae and Stictidaceae. The former reference was due to the tendency of the hymenium to turn black after long weathering. Specimens have recently been submitted to Mrs. Flora W. Patterson, of the Bureau of Plant Industry, who states—

> We incline toward placing it in Stictidaceae, but find no perfect description in either the old or new genera of any family.

[1] Weir, J. R. A botrytis on conifers in the northwest. *In* Phytopathology, v. 2, no. 5, p. 215. 1912.

In the writer's opinion it plainly belongs in Stictidaceae, a view likewise held by Dr. E. J.Durand, to whom material was submitted. A detailed description of the fungus follows:

Apothecia embedded in the epidermal layer of the substratum, lenticular or oblong-elliptical, scattered, uniseriate, or more frequently biseriate, on under side of needle, sometimes confluent in two rows on each side of the midrib, rarely situated on the middle nerve, usually arranged at the edge of the needle, causing a discoloration of the tissues on the upper side. Epidermal covering of the apothecia rupturing by an irregular longitudinal slit exposing the brownish convex disk, line of rupture more frequently to one side or rupturing from the center in lobes in single or isolated apothecia. Asci cylindrical to clavate (25) 15. 7 to 19.4 μ by 113.9 to 153.3 μ (15.7 to 16.5 μ by 125.9 to 129.2 μ), abruptly rounded above, pedicels short, 8-spored, with filiform hyalin paraphyses slightly swollen at tips. Ascospores irregularly biseriate or more frequently obliquely uniseriate, hyalin, 1-celled, oblong, rounded at the ends, rarely obtusely pointed, more frequently constricted in the middle (80) 6.6 to 7.4 μ by 18.2 to 19.8 μ (7.0 to 7.4 μ by 18.2 to 19.4 μ). The pore of the ascus is colored blue by iodin.

SUMMARY

(1) For the past three seasons a needle blight of the Douglas fir has caused great damage to young trees and seedlings in the Northwest. The disease is common both in the nursery and in the forest.

(2) The systematic position of the causal fungus has not been satisfactorily determined, but it is referred for the present to the Stictidaceae. The fungus is vigorously parasitic and is apparently confined to the Douglas fir. It has been found throughout the entire Northwest.

(3) Spraying with a solution of soap and Bordeaux mixture (4–4–50) gives indication of being a successful means of controlling the fungus.

PLATE 12

A.—The needle-blight fungus as it appears normally infecting the 1-year-old needles of *Pseudotsuga taxifolia*. About natural size.

B.—An 18-year-old Douglas fir, showing the thin foliage due to infection with the needle-blight fungus.

A

B

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A SUBSTITUTE FOR LITMUS FOR USE IN MILK CULTURES

By WM. MANSFIELD CLARK and HERBERT A. LUBS, *of the Research Laboratories, Dairy Division, Bureau of Animal Industry, United States Department of Agriculture*

The color changes which occur in litmus-milk cultures may be due not only to changes in the hydrogen-ion concentration of the medium but to reduction or even destruction of the dye. Thus, in any given case there may be obtained a composite picture which may happen to be more or less characteristic of a particular organism but which at the same time is difficult to analyze. It is not to be denied that such a complex picture may be of some value to a trained observer, but its complexity obscures that clear and simple view which should distinguish a good cultural test.

Dibromoorthocresolsulfonphthalein, which the writers have described as a reliable and brilliant indicator for the colorimetric determination of hydrogen-ion concentration,[1] is reduced with difficulty. In most cases it may be used even in the presence of active bacterial growths without being appreciably reduced, and it will therefore continue to show changes in the reaction of the medium without the confusing effect of reduction.

For laboratory parlance the writers have suggested that dibromoorthocresolsulfonphthalein be called "bromcresol purple." Its preparation has been described in previous papers,[2] and it may now be purchased in this country; but in purchasing this compound the full chemical name should always be used. For ordinary indicator purposes a 0.04 per cent aqueous solution of the monosodium salt is recommended, but as a stock solution for the present purpose a solution of the salt containing 0.5 per cent of the acid is suggested.

This solution may be prepared as follows: 0.5 gm. dibromoorthocresolsulfonphthalein should be ground to a fine powder in a glass mortar and 14 c. c. of *N/10* sodium hydroxid added, and the mixture stirred well. This is approximately 1.5 equivalent parts of sodium hydroxid. The

[1] CLARK, W. M., AND LUBS, H. A. THE COLORIMETRIC DETERMINATION OF HYDROGEN ION CONCENTRATION AND ITS APPLICATIONS IN BACTERIOLOGY. PT. I–III. *In* Jour. Bact., v. 2, no. 1, p. 1–34, 4 fig.; no. 2, p. 109–136, fig. 5–7; no. 3, p. 191–236, fig. 8. 1917. References, v. 2, no. 3, p. 233–236.

[2] LUBS, H. A., AND CLARK, W. M. A NOTE ON THE SULPHONEPHTHALEINS AS INDICATORS FOR THE COLORIMETRIC DETERMINATION OF HYDROGEN-ION CONCENTRATION. *In* Jour. Wash. Acad. Sci., v 6, no. 14, p. 481–483. 1916.

mixture should be diluted to about 90 c. c. with distilled water, shaken until solution is complete, and then made up to 100 c. c. with distilled water. The manufacturer should furnish material which when treated in this manner will provide a clear solution free from the odor of cresol.

A satisfactory concentration for coloring milk is about 0.005 per cent, and is obtained by adding 10 c. c. of a 0.5 per cent solution to 1 liter of milk. Since the molecular weight of the sodium salt of dibromoorthocresolsulfonphthalein is 562, the above-described concentration is approximately M/10,000.

The color of milk containing about 0.005 per cent of bromcresol purple may be approximately described as a deep glaucous gray.[1] After sterilization for 20 minutes at 15 pounds' pressure, the color is a tea-green.[2] When an alkali formation occurs, the color goes through a series of blues, while in the case of an acid fermentation the color changes to yellow. If the milk is digested, the color of the indicator stands out clearly, but it is difficult to describe by reason of the dichromatic nature of the transmitted light, which the writers have explained in a previous paper.[3]

The cost of the new indicator is a factor which must be considered by those who use extensively an indicator in milk cultures. In 1916 a manufacturer made for the writers some bromcresol purple at $2 a gram. At that price it costs 10 cents to color a liter of milk with the concentration of dye which is recommended. In the same year they purchased azolitmin at $5 an ounce. If that dye is used in the customary concentration of 0.1 per cent, it costs, at the price given above, about 17½ cents to color a liter of milk. Crude litmus is, of course, very much cheaper, but the quality purchasable is not very satisfactory. As is well known, litmus and azolitmin have lost prestige in the modern chemical laboratory, and for that reason there is little incentive for the manufacturers to improve the quality of the samples placed on the market.

It should be noted that the price paid for bromcresol purple was out of all proportion to the current costs of the raw materials at the time and to the cost of manufacture. It represents the trouble and risk in manufacturing and marketing a new product for which at the time the demand was very small. A fair estimate of the cost can not be made at present.

When litmus milk is sterilized, the litmus undergoes a temporary reduction. In some laboratories whole milk is used for special purposes. In this case the cream layer which is formed delays the diffusion of oxygen, and the reoxidation of the dye becomes a slow process, involving considerable delay in the use of the litmus-milk tubes. Bromcresol purple does not suffer such a reduction, and consequently milk tubes containing it are ready for use directly after sterilization.

[1] RIDGWAY, Robert. COLOR STANDARDS AND COLOR NOMENCLATURE. Washington, D. C., 1912.
[2] Idem. Pl. 47.
[3] CLARK, W. M., AND LUBS, H. A. 1917. Op. cit.

The range of P_H within which bromcresol purple exhibits its color changes is well suited to the P_H values of milk cultures, which is not entirely true of litmus and azolitmin. There are found in the literature various directions for "adjusting the reaction" of milk in order to bring out a favorable color with litmus or azolitmin.

Litmus is seldom pure, and even azolitmin has been reported to be of uncertain composition. Bromcresol purple can be obtained in crystalline form. When one considers the relatively high concentrations in which litmus must be used and the very high dilutions in which bromcresol purple is serviceable, it is evident that, if the introduction of impurities is to be avoided, the advantage of bromcresol purple is great.

The impurity in a litmus preparation often changes the P_H of the milk to which it is added. Because of considerable variation in the quantity of impurity, it is difficult to obtain the same color in different batches of litmus milk even when the milks, the actual concentration of dye, and the time and temperature of sterilization are constant. Since fresh milks are fairly constant in their initial P_H, while litmus preparations have variable neutralizing power, Dr. P. Rupp, of the Dairy Division, has found it advisable to adjust the neutralizing power of the litmus solution rather than to attempt any adjustment of the P_H of the milk either before or after the addition of the litmus solution. By this procedure he has been able to increase very materially the reproducibility of the color in litmus milk.

Bromcresol purple is obtainable now in very pure form, and the ability of a low concentration of its sodium salt or of the acid itself to change the P_H of milk is practically nil; consequently, when it is added to milk in the concentration recommended, no adjustment of the dye solution, of the milk, or of the mixture is necessary.

Particular attention should be called to the fact that milk is not suited to accurate estimations of its hydrogen-ion concentrations by the colorimetric method. This is chiefly because the turbidity of milk is so intense that it can not be compensated for in making the comparisons with the clear, colorless standards. There is also a probable "protein" error. None of the methods which we have successfully applied to other colored and turbid-culture media has proved to be very successful when applied to milk. These considerations reduce but do not wholly destroy the value of comparative measurements. Even though a definite P_H value can not be assigned to the reaction in any particular culture, the direction of the fermentation and, roughly, its intensity can still be determined.

A much more serious aspect of the subject is the considerable change in P_H which occurs when milk is sterilized and the consequent difficulty in reproducing a particular initial color in different batches. Quite aside from the temporary reduction which occurs when litmus milk is sterilized, there is a permanent color change which must be ascribed to the change in the hydrogen-ion concentration of the milk. A similar change in color will be observed when milks containing bromcresol

purple are sterilized. That this is due to change in hydrogen-ion concentration is shown by the following experiment: Two equal portions of the same sample of fresh-skimmed milk were autoclaved, one sample with bromcresol purple present, the other with the indicator absent. After sterilization the uncolored sample received the same quantity of indicator that had been added to the first sample. The two samples of heated milk then had the same color. Both showed in like degree a change from the color of an unheated control containing the same concentration of indicator. The change in P_H which occurred during sterilization was measured by means of the hydrogen electrode. The value of the unheated sample was $P_H = 6.60$, while that heated in the autoclave at 17 pounds for 15 minutes was 6.36. When the unheated milk was acidified until its P_H value was close to that of the heated milk, the two samples matched almost perfectly in their color with bromcresol purple.

These observations indicate quite conclusively that the color change which occurs when milk containing bromcresol purple is heated is due to a change in the hydrogen-ion concentration of the milk, and that it is not due to an alteration of the indicator itself. The same conclusion holds for the permanent color change in litmus milk. This is supported by the fact that the different degrees of color change which occur when milks are heated for a longer or shorter period or at higher or lower temperatures are proportional to the changes in hydrogen-ion concentration accompanying these treatments. It should be noted that in the more severely treated milks there is a coloration of the milk itself, which is superimposed upon the color of the indicator.

It is also important to note that the changes in t e reaction of milks which are brought about by sterilization may be considerable. It has been stated above that a sample of milk with a P_H value of 6.60 was changed to $P_H = 6.36$ during 15 minutes' sterilization at 17 pounds' steam pressure. A duplicate sample, when held for 15 minutes longer at that pressure, had a P_H value of 6.13. What the variation may have been in milks of diverse qualities, treated with litmus solutions of various degrees of impurity, adjusted with different additions of alkali or acid, and heated at various pressures for different lengths of time, it is quite impossible to say. The variations may not have been important for crude cultural tests of most organisms, but in the study of certain ones it is entirely possible that at times the reaction was brought to the border of or placed outside the optimum range for growth.

In the utilization of milk as a culture medium it may be foun_ advantageous in particular instances to adjust its initial P_H to some point other than that obtained in sterilized fresh milk. The writers have found, for instance, that if milk is to be brought to P_H 7.0 when sterilized, bromthymol blue is more serviceable than bromcresol purple. For most purposes it will be found advantageous to adhere to the use of fresh, unadjusted milk containing some definite quantity of bromcresol purple. If, then, the temperature and time of sterilization are kept constant, the

color of different batches will be reproducible. This implies that the initial P_H will be the same in all cases. So far as this affects the growth and metabolism of a culture, it is important that it should be reproducible, which it certainly is not when the procedures that have been used in the preparation of litmus milks are modified at will, with no very clear conception of the important aims.

The possible usefulness of diluted milk has not been fully appreciated. While our own experiments have been very few, the writers think that one or two of the more general aspects of the subject are worthy of notice.

Dilution of milk tends to raise the P_H. In certain instances this may be a distinct advantage and a better way of adjustment than the addition of alkali. In one preliminary experiment it was found that the change in P_H during the sterilization of a milk diluted five times was less than that in the undiluted sample. The most suggestive aspect of the subject is the relative buffer effects in diluted and undiluted milk. The buffer effect of milk is considerably higher than that of most culture media.[1] Consequently a culture must elaborate an unusual quantity of acid or alkali to induce a given change in P_H and a consequent change in the color of an indicator. By diluting the milk the relative buffer effect is lowered, and a proportionally smaller degree of acid or alkali fermentation is required to induce a given change in the indicator color. Dilution also permits a better view of the color.

Obviously such facts are not the only ones to be considered, and in lieu of sufficient data to permit a systematic treatment of the use of diluted milk, the writers will confine themselves to the presentation of a series of experiments with cultures in undiluted skim milk in which the relative value of litmus and bromcresol purple was tested.

The organisms used were several acid-forming cultures of *Bacillus coli*, *B. aerogenes*, *B. bulgaricus*, and streptococci, three alkali producers of Mr. S. H. Ayers, of the Dairy Division, some cultures of *B. proteus*, and the following pathogenic bacteria kindly sent to the writers by Prof. C. E. A. Winslow from the collection of the American Museum of Natural History:

Bacillus paratyphi	"B"	No. 22
Do.	"B"	No. 323
Do.	"A"	No. 16
Do.	"A"	No. 294
Bacillus typhi		No. 607
Do.		No. 608
Bacillus enteritides		No. 18
Do.		No. 25
Bacillus dysenteriae	"Strong"	No. 196
Do.	"Shiga"	No. 197
Do.	"Flexner"	No. 110
Do.	"Kruse"	No. 121

[1] CLARK, W. M. "THE REACTION" OF BACTERIOLOGIC CULTURE MEDIA. *In* Jour. Infect. Diseases, v. 17, no. 1, p. 109–136, 7 charts. 1915.

Observations were also made with a strain of the anthrax bacillus furnished by Dr. R. A. Kelser, of the Bureau of Animal Industry, and a strain of *B. abortus* given by Miss Alice C. Evans, of the Dairy Division.

Observations were made at 20, 26, 48, and 72 hours after inoculation and from then on at various periods for a month. Incubation temperatures were appropriate to the organisms studied.

It is almost impossible to describe the color of indicator solutions by means of Ridgway's color charts,[1] and there are no standards which may be used satisfactorily with milk for determining colorimetrically P_H values. The writers must therefore be content with saying that no change was observed in the litmus-milk cultures which could not be seen so well with milk colored with bromcresol purple. In a few instances a more rapid change was observed in one case than in another, but this may be ascribed either to the peculiarity of an individual culture or to a more favorable initial P_H in the one case or the other.

A noteworthy example of the higher value of bromcresol purple was observed when comparing cultures of *B. coli*, streptococci, and *B. bulgaricus*. As the senior writer noted in a former paper,[2] *B. coli* cultures do not attain the same hydrogen-ion concentration in milk that they attain in other media. The writers now observe that even when they bring milk to the point of coagulation the bromcresol purple is left with a tinge of glaucous gray. Streptococcus cultures which in milk arrive at a higher hydrogen-ion concentration give to the bromcresol purple a clear cream color. Cultures of *B. bulgaricus* produce so much higher reaction that the cream color of a streptococcus culture gives place to a maize-yellow.[3] So beautiful a graduation of color change is entirely lost in litmus cultures.

In those cases in which a digestion of the milk occurs there is a very marked change in the quality of the color, owing to the fact that as turpidity is removed greater depth of the solution is observed, and, instead of the transmitted blue of the indicator being dominant, as it is in thin layers of solution, the transmitted red becomes more noticeable. This change may prove confusing to one who is unfamiliar with this indicator, but one who is familiar with its colors in various solutions and in the colorless standards of known P_H may still follow approximately the degree of alkali or acid production.

The most noteworthy advantage of bromcresol purple observed in this series of comparative tests with litmus was found to be the resistance of the new indicator to reduction. In very few instances was any serious reduction or destruction detected. While litmus seemed to be decomposed in a variety of ways with the production of mere muddy colors, in many instances bromcresol purple continued to indicate changes in P_H,

[1] RIDGWAY, Robert. Op. cit.

[2] CLARK, W. M. THE FINAL HYDROGEN-ION CONCENTRATION OF CULTURES OF BACILLUS COLI. *In* Jour. Biol. Chem., v. 22, no. 1, p. 87–98, 1 fig. 1915.

[3] RIDGWAY, Robert. Op. cit., pl. 4.

as a good indicator should. This alone is a sufficient reason for recommending that it be substituted for litmus in milk cultures and in similar instances in which it is considered advisable to have an indicator present during a fermentation.

SUMMARY

The color changes which occur in litmus-milk cultures may be due to changes in the hydrogen-ion concentration of the medium or to reduction or even destruction of the dye. If it is the degree of acid or alkali fermentation which is sought, it is advisable to use an indicator which will not be affected except by a change in the hydrogen-ion concentration. Dibromoorthocresolsulfonphthalein, for which the short name bromcresol purple is suggested, fulfills this condition.

Litmus undergoes a temporary reduction during sterilization in the presence of milk. Bromcresol purple does not.

The coloring power of litmus is relatively weak; bromcresol purple in very high dilution is useful.

Litmus and azolitmin are indicators of uncertain composition; bromcresol purple is a definite individual compound obtainable in crystalline form and therefore reproducible. Its cost is not excessive.

The impurities of litmus preparations vary in their effect upon the P_H of milk and often necessitate elaborate adjustment either of the litmus solution, of the milk, or of the mixture if reproducible color is to be obtained. Bromcresol purple, on the other hand, may be used with the assurance that, if other conditions are constant, it will always produce the same coloration.

Some of the difficulty experienced in reproducing a particular initial color with either indicator is shown to be due to the changes in P_H which occur when milk is sterilized by heat.

The comparative value of litmus and bromcresol purple in milk cultures was tested with a variety of organisms. It was found that no change in reaction could be observed with litmus which could not be followed equally well with bromcresol purple. In many instances litmus was rendered useless by reduction or destruction while bromcresol purple continued to act as a true indicator of the hydrogen-ion concentration.

MOVEMENT AND DISTRIBUTION OF MOISTURE IN THE SOIL

By F. S. HARRIS, *Director and Agronomist*, and H. W. TURPIN, *Fellow in Agronomy*, *Utah Agricultural Experiment Station* [1]

INTRODUCTION

Ever since agriculture has been the subject of scientific study, soil moisture in its various relations has been given a great deal of attention. Following the tremendous development of the bulb industry in Holland during the seventeenth century, and in view of the classic experiment of Van Helmont, water was for a generation thought to be the "real food of plants" and practically the only substance absolutely necessary for their life. This idea naturally turned the attention of workers in agriculture toward the moisture of the soil.

Probably no other factor so often limits crop production as does soil moisture. It not only enters intimately into the plant as a food and a carrier of other foods, but it also is the means by which the foods of the soil are made available to the plant. In some cases it is the lack of moisture and in others the presence of excessive quantities that causes the difficulty. It is not often that a crop has, during its entire life, just the quantity of water that best serves its needs.

In the present paper, in which the results of thousands of determinations are presented, an attempt has been made to throw light on a number of the important phases of soil-moisture movements. Practically all these results are presented in diagrams which make relations more apparent than does the study of long tables. Much valuable experimental material is forever buried in complex tables because the figures are so difficult to analyze that the reader seldom sees more than the most apparent relationships.

REVIEW OF LITERATURE

HISTORICAL DEVELOPMENT OF SOIL-MOISTURE STUDIES

Opinions are at present not very concordant as to the extent of capillary movement in the soil and as to how the moisture finally distributes itself under field conditions.

The pioneer of soil-moisture work in America was King (13–15)[2] who, from field investigations during a number of years, concluded (16, p. 105) that "what evidence we have goes to show that subsoils 6 and 7 feet

[1] The authors wish to acknowledge their indebtedness to the various members of the staff of the Department of Agronomy who have contributed to this work in field, laboratory, and office.

[2] Reference is made by number to "Literature cited," p. 153–155.

below the surface may contribute large amounts of water * * * for the use of vegetation at the surface." He (21) also found that the loss of moisture due to evaporation at the surface of columns of moist soil caused capillarity to act through a depth of 10 feet in 10 days.

From his studies with long columns of soil, King (20, 21) decided that the water in moist soils tends to distribute itself with the most moisture at the bottom of the column and the least above, regardless of the previous distribution.

The work of Briggs (4) and Briggs and Lapham (5), on the other hand, indicates that the final distribution leaves the most moisture nearest the source of supply and the least farthest away. They believe the movement to be due to the difference in the curvature of the soil-moisture films. The resistance of this film to a tangential shearing stress prevents an excessive thinning of the film, thereby checking the tendency for an equal distribution of water applied at a given point.

The irrigation experiments of Loughridge (24) and Widtsoe and McLaughlin (32) show that most of the soil moisture is found nearest the source of supply, no matter in what direction the movement takes place. The latter investigators (32, p. 268) also found that "when water is abstracted from a soil the loss is felt to every depth reached by the soil augers."

That considerable movement of water takes place in moist soil was demonstrated by Alway and Clark (2), who found that loss of water from the surface of soil having but 12 per cent of moisture was felt to a depth of 3 feet. Lynde and Bates (25) and Lynde and Dupré (26) think that osmosis may cause a considerable movement of soil moisture.

It has been demonstrated by Bouyoucos (3) that a change in temperature will occasion a large movement of moisture in unsaturated soil.

Burr (7) found that very little moisture was brought to plant roots by capillarity. Away from a source of soil water, in a soil partially dry, capillary movement was not detected.

FORCES ACTING ON SOIL MOISTURE

That discordant results in soil-moisture investigations should be found is not strange when it is remembered how complex is the soil itself and how many are the forces acting on soil moisture.

Bouyoucos (3) has pointed out that soils have a great attractive and adhesive force for water. The moisture equivalents found by Briggs and McLane (6) give an idea of the magnitude of these forces. As has been stated, osmosis may play an important part in the movement of soil moisture.

Viscosity, concentration of soil solution, surface tension, and moisture-film curvature are all important in soil-moisture movement, according to Briggs (4) and Briggs and Lapham (5).

Effect of Manure

Whitney (30) showed that manure lowers the surface tension of the water near the surface so that the moisture of the upper soil moves into the lower layers where the surface tension is greater. The same authority (31) later concluded that the urine in the manure has a tendency to deflocculate the soil particles, thereby preventing the loss of moisture by downward movement. Experiments in the field and in cylinders by King (16) indicate that manure has considerable influence in increasing the water content of the soil, even down to a depth of 4 feet, and that this influence is still exerted a year after manuring. He (17) later states that the upper 3 feet of manured fallow land will contain much more moisture than corresponding depths of unmanured soil. He also shows that manure tends to decrease the water content of the second 3 feet in depth. Wetting the surface of sand with liquid leached from manure reduced the capillary rise by 16 inches and the rate of evaporation from the surface by 49.6 per cent. Snyder (28) found that manuring increased the soil moisture during a period of drought.

Effect of Cultural Methods

King's investigations (16) indicate that "thorough cultivation keeps the soil below the surface foot cooler, thereby materially increasing the capillary power. The capillary force being stronger, the soil moisture is moved upward faster and through longer distances." He (18) also found the soil below a 3-inch cultivation to be more moist than that below a 1.5-inch cultivation, although the third and fourth feet showed reversed results. Experiments by Chilcott and Holm (9) confirm King's results. King's laboratory experiments (22) show a 1-inch cultivation to be the most effective for checking evaporation.

Field investigations by Kedzie (12) indicate that to a depth of 16 inches cultivated plots had 3 per cent more moisture than naked fallow, and that during a period of drought the former actually gained 2 per cent of moisture in the top foot.

Late in the season Hays and Smith (10) found the cultivated plots had no more moisture than the uncultivated fallow. The soil under straw mulches 4 inches deep contained 5 per cent more moisture than bare fallow. Cardon (8) observed no advantage in deep plowing or subsoiling over shallow plowing, so far as moisture conservation was concerned. Cultivated fall-plowed fallow maintained practically the same water content throughout the season, while in fall-plowed uncultivated plots water rapidly decreased, owing to winds. Spring-plowed cultivated fallow showed no difference in water content when compared with uncultivated spring-plowed plots in which the weeds were killed by spring plowing.

The work of Burr (7) showed that the effectiveness of summer tillage depended on the presence or absence of a growing crop, and weeds cause

a greater loss of soil moisture than evaporation from a bare soil. Small grains were found to dry out the soil more completely than cultivated crops. He found straw mulches, deep cultivation, and shallow cultivation to rank in efficiency in the order named. Rain water penetrated more rapidly into a wet than into a dry soil, the latter being wetted to a depth of 6 inches by 1 inch of rain.

Effect of Irrigation

The distribution of soil moisture following an irrigation or rainfall has been studied by many investigators. King (14) observed a very slow rate of penetration in a gravelly clay after 1.4 inches of rain, and the lateral movement did not exceed 3 feet. Loughridge (24), working with sandy loam, found the downward movement of irrigation water very irregular in its rate and in the amount retained at various depths. The lateral movement of water from the furrows did not exceed 2 feet, and the relative proportion of dry soil to that wetted decreased with the depth at first, then increased.

Elaborate experiments by Widtsoe and McLaughlin (32) brought out the following: Irrigation water penetrates very rapidly to a depth of 6 feet; with any amount of irrigation the percentage distribution is always the same for each foot shortly after irrigation; it is believed that in an unsaturated soil where f is the percentage of water at the depth indicated by d ($d_1 = 1$ foot deep), and K is the percentage of water which must be satisfied before rapid movement will take place, the following law holds for the distribution of moisture in a uniform soil:

$$(f - K)\, d = (f_1 - K)\, d_1 = (f_2 - K)\, d_2 = \text{constant}.$$

The lateral movement of water increases with depth; in Greenville loam the movement of water is slow, with less than 12.75 per cent of moisture. Experiments by Allen (1) indicate that with 2.5-, 5.0-, and 10-inch irrigations the same amount of water is retained in the upper 4 feet of soil after 24 hours.

Effect of Soil Type

Briggs (4) has pointed out that coarse and fine soils having the same percentage of water will not be in moisture equilibrium. Such soils when brought together would experience a movement from the coarse into the fine soil. King's percolation experiments (19, 20, 21) with long columns of sand showed that sand will retain very little capillary moisture—sometimes less than 2 per cent. Reynolds (27), Hilgard (11), Tulaykov (29), Willard and Humbert (33), and Wollny (34) agree that the capillary rise is always least in the coarse soil and greatest in fine soils, but the rate of rise at first is directly proportional to the coarseness of the particles. Later the reverse is true.

Effect of Initial Percentage and Gravity

Briggs and Lapham (5) found the rise of moisture was 4.5 times greater in a moist than in a dry soil, while Krakov (23) showed the rapidity and height of capillary rise to be inversely as the soil moisture. Wollny (35) declares that capillary rise and percolation of water in the soil declines in rate as the water content of the soil diminishes. Krakov (23), as well as Alway and Clark (2), has shown that moisture moves more rapidly through the soil when assisted by gravity than when moving upward against it.

FIELD STUDIES

CROPPED AND FALLOW SOILS

Under Irrigation

This experiment was conducted from 1913 to 1915, inclusive, on the Greenville Experiment Farm at North Logan, Utah. The plots used for the experiment were 61 G to 73 G, each of which was subdivided into 6 parts receiving different treatments. As divided, there were 36 subplots cropped to corn and 42 uncropped, each containing the irrigation and manuring treatments divided as much alike as possible. Fairly well rotted cow and horse manure was applied to the manured plots early in the spring, and later it was disked and plowed in.

The quantity of irrigation water varied from none to 40 inches and was applied from wooden flumes as follows:

For cropped plots receiving 5 inches, 2½ inches each at beginning of tasseling and roasting-ear stage.

For plots receiving 10 inches, 5 inches each at the above stages.

For plots receiving 20 inches, 5 inches each when the plants were 12 inches high, at the beginning of tassel, at bloom, and at roasting-ear stage.

For plots receiving 30 inches, 5 inches each when plants were 12 inches high, 10 days later, at beginning of tassel, at bloom, at roasting-ear stage, and 10 days later.

For plots receiving 40 inches, applications began when plants were 12 inches high, and 5 inches were applied each week until all the water was added. The fallow plots were irrigated at the same times as the cropped.

A detailed description of the treatment of these plots may be had in Bulletin 133 of the Utah Experiment Station.

In this experiment the plots were sampled in the fall to compare the effect of the corn and fallow on the final distribution of moisture. The samples were taken in 1-foot sections with a soil auger, each plot being sampled in three places. These were then mixed into a composite sample.[1]

Figure 1 gives the average distribution of moisture to 10 feet in depth for all fallow and cropped plots for the 3-year period. From this figure it will be seen that the fallow has considerably more moisture in the upper 7 feet than the cropped, particularly in the sixth and seventh feet,

[1] For a detailed study of the methods used in sampling, the reader is referred to Bulletin 115 of the Utah Experiment Station (32).

with a gradual decrease in this difference toward the surface. Below 7 feet, however, the cropped plots show a larger content than the fallow ones. The larger difference in moisture content between cropped and fallow plots in the upper layers of soil is readily explained by the fact that the crop draws most water from that zone. The action of the crop in lowering the moisture content of the soil is quite distinct although rather peculiar.

The lowest moisture content is found in the cropped plots in the fifth and sixth feet, with an increase below and above that depth. In the

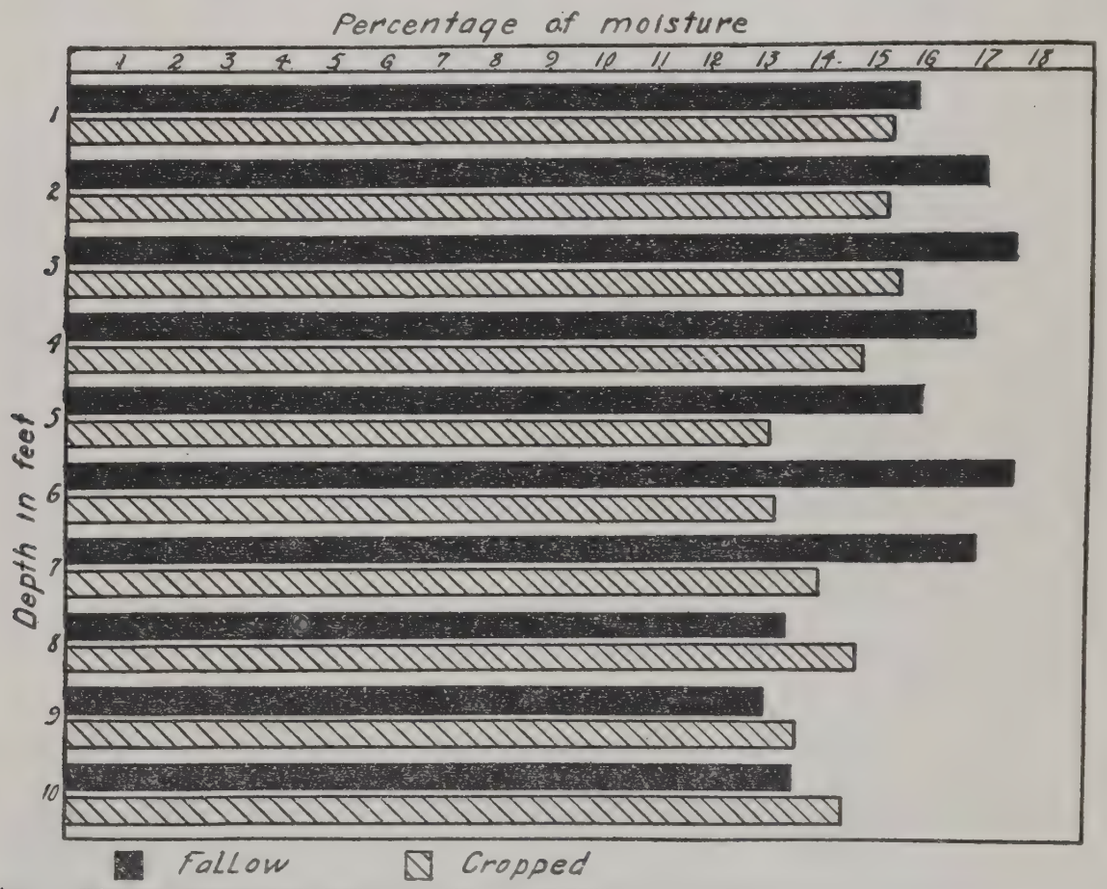

FIG. 1.—Diagram showing the effect of cropping and fallowing under irrigation on the distribution of soil moisture in the fall to a depth of 10 feet. Average of three years.

fallow, on the other hand, it is in the sixth and seventh feet that the largest moisture content is found, a rapid decrease taking place below that depth.

UNDER DRY-FARMING

This test was carried out at the Nephi Substation between the years 1908 and 1912, inclusive. Cropped plots which were devoted to a rotation including corn, peas, potatoes, and wheat are here compared with fallow plots rotated with wheat. Except for the wheat, all plots were cultivated, so that the cropped plots are strictly comparable with the fallow ones.

The plots were sampled in duplicate in the spring about May 21, in the summer about June 16 and July 21, and in the fall about the first week in October.

The results of the 5-year averages for the corn, peas, and potatoes and the fallow are presented in figure 2, giving the distribution of moisture by foot sections for the four periods.

The figure shows that during the spring, until after June 16, there was little difference between the moisture in the fallow and cropped plots, but thereafter the difference was in favor of the fallow. In October every foot in depth of the fallow had a higher moisture content than the cropped soil. For all periods the least moisture was found in the first, the fourth, and the fifth feet. The first foot is the only one showing much variation in moisture during the season. In all cases the fluctuation in the fallow was less than that in the cropped soil. As an average for all feet the moisture at the end of the season was only slightly less than that in the spring.

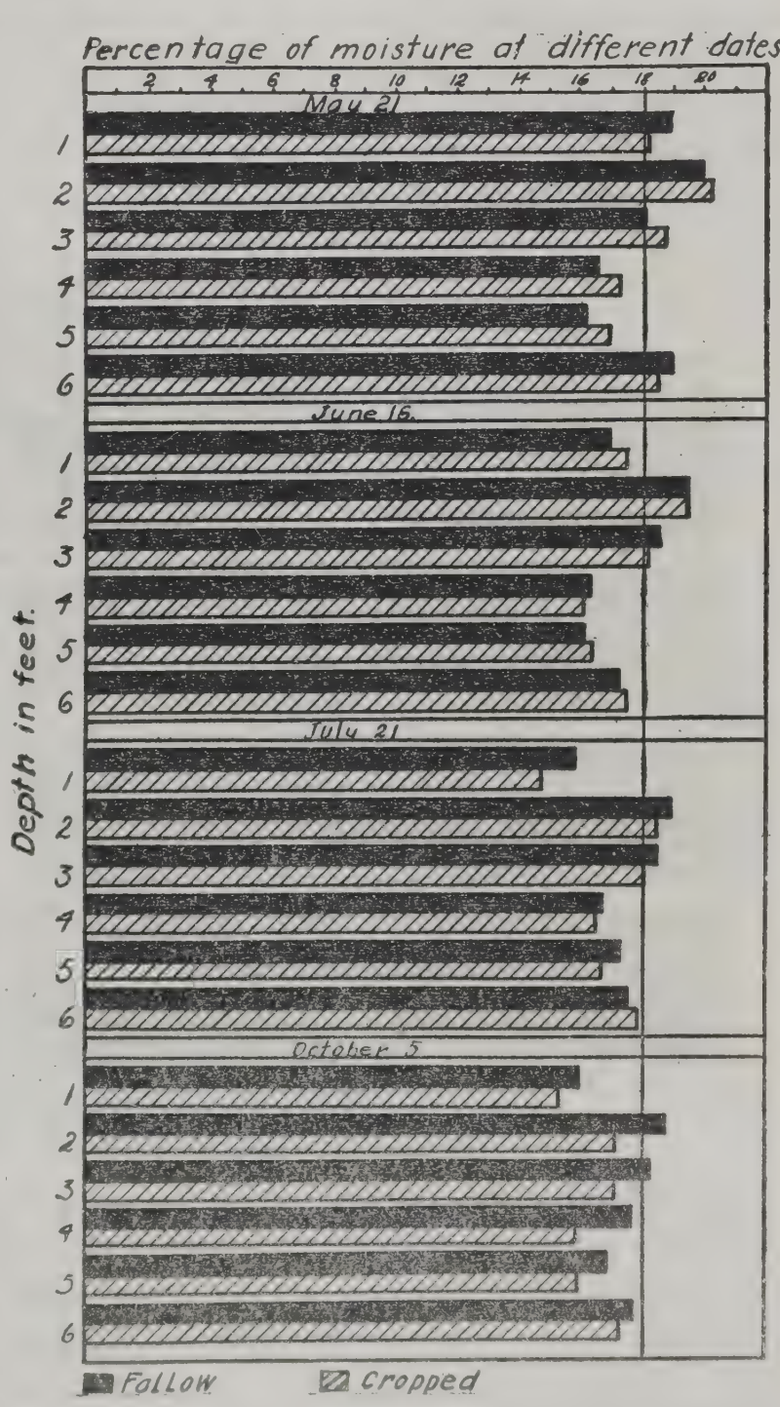

FIG. 2.—Diagram showing the effect of intertilled cropping and fallowing under dry-farming conditions on the seasonal distribution of moisture in the soil to a depth of 6 feet. Average of five years.

KIND OF CROP UNDER DRY-FARMING CONDITIONS

This study was conducted at the Nephi Substation for the years 1909 to 1914, inclusive, on the plots described in the experiment on the effect of cropping and fallowing. The samplings in this case were taken but three times: Once in the spring, once in the summer, and once in the fall.

In figure 3 is presented the average moisture distribution for corn, potatoes, peas, and wheat in the spring, summer, and fall for six years.

In the spring there was scarcely any difference between the moisture contents in the different cropped plots, wheat, if anything, having the most and corn the least moisture. The wheat plot had the least quantity of water in the summer period, corn, peas, and potatoes following in order. In the fall, although there had been a considerable loss since summer, the general relationship was the same except that the plot in potatoes had lost a little more moisture than that in peas.

As the season progressed, the moisture in the wheat plot tended to distribute itself, with the largest content at the sixth foot and the least near the surface. This was also the case with the corn and potatoes, but was not so evident with the pea plot.

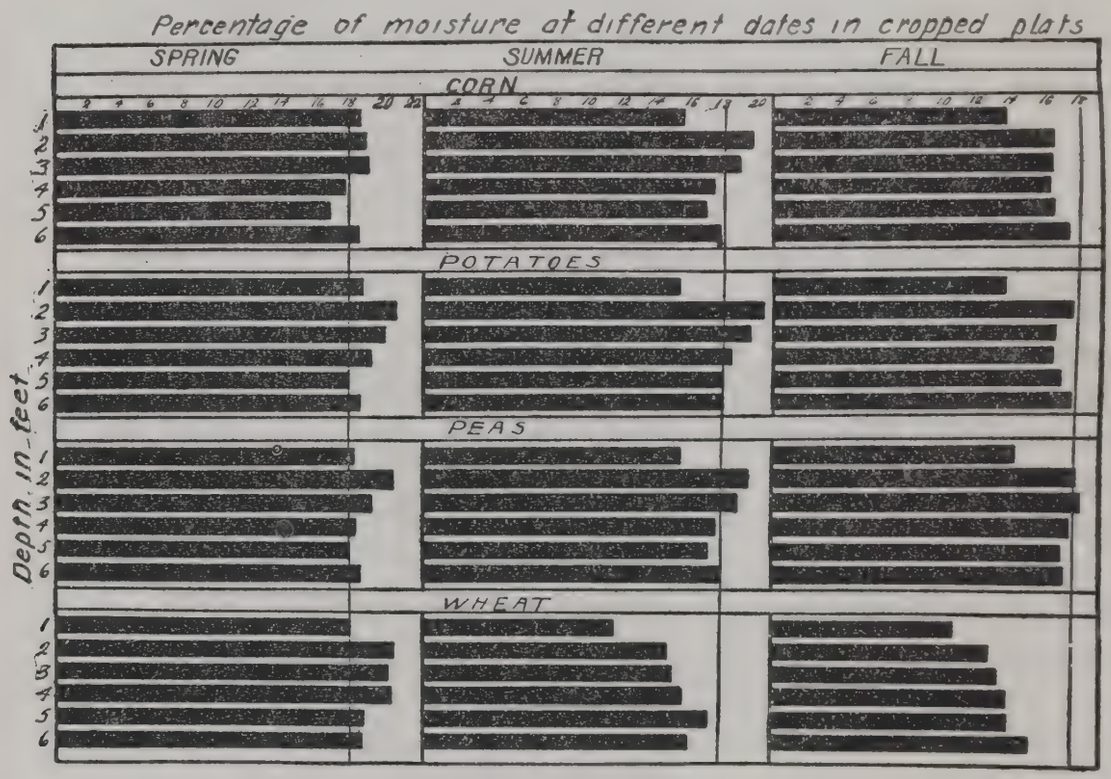

FIG. 3.—Diagram showing the effect of different crops under dry-farming conditions on the seasonal distribution of moisture in the soil to a depth of 6 feet. Average of six years.

The middle sections of the soil in the spring had the most water, with the least in the first and fifth feet. This distribution was found in the summer for all plots except the wheat, where the moisture increased gradually with depth. In the fall the moisture in the wheat and corn plots increased with depth, while the peas and potatoes showed the same relation between the moisture of each foot that they did in the spring. All plots had the greatest loss of moisture in the first and second feet with least in the fifth and sixth.

EFFECT OF MANURE UNDER IRRIGATION

Studies of the influence of manure were made for the three years from 1913 to 1915, inclusive, on the same plots of the Greenville Farm described in the experiment on the effect of cropping and fallowing under

irrigation conditions. The quantities of manure applied were none, 5 tons, and 15 tons.

Figure 4 gives the effect of these quantities of manure on the moisture in the fall to a depth of 10 feet. This figure brings out a remarkable difference between the manured and unmanured plots. For the unmanured plots, both cropped and fallow, the moisture approached a maximum in the second, third, sixth, and seventh feet, with a rapid decrease to the tenth foot. In the manured fallow soil the maximum

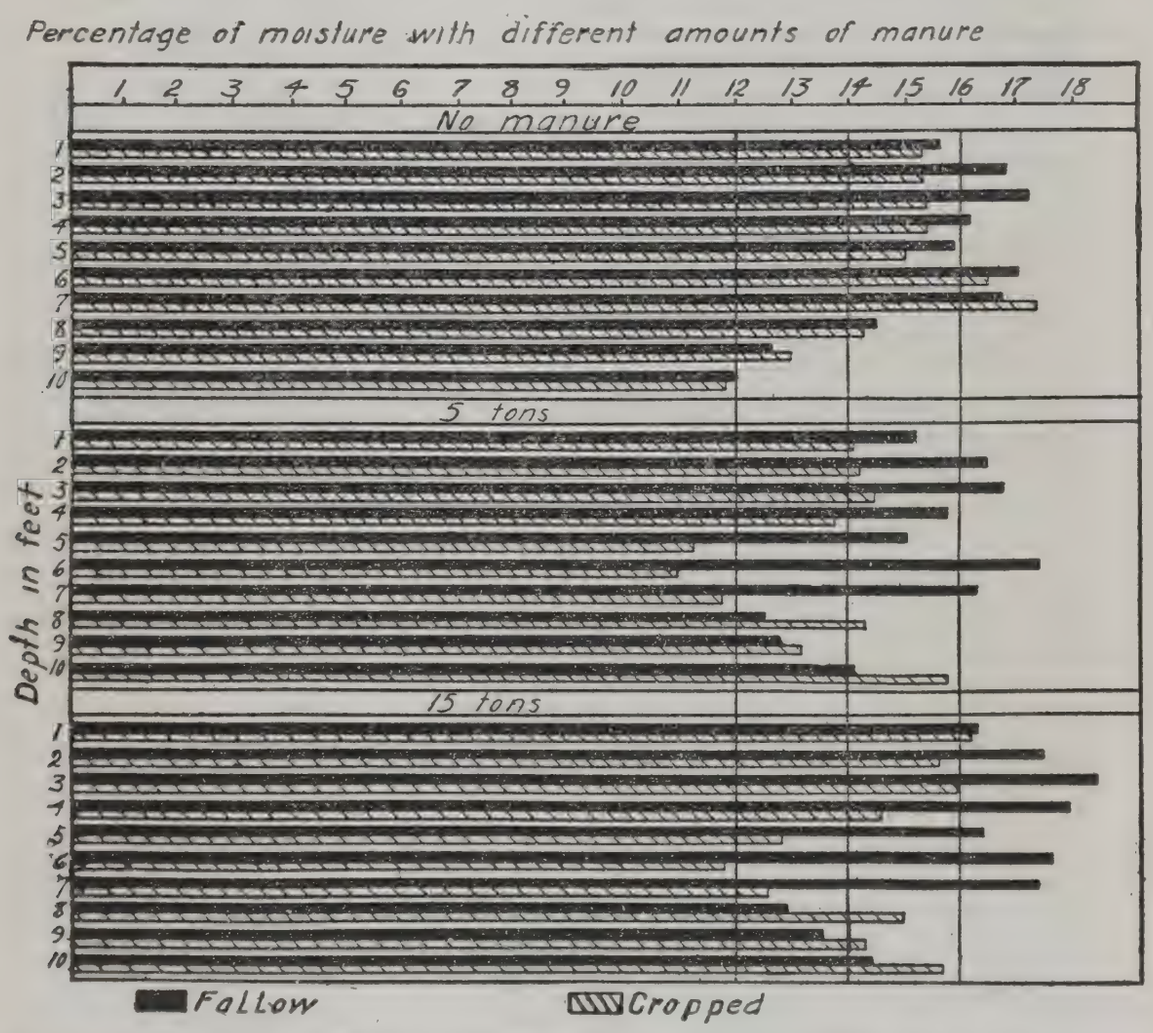
Percentage of moisture with different amounts of manure
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18
No manure
5 tons
15 tons
Depth in feet
1 2 3 4 5 6 7 8 9 10
Fallow
Cropped

FIG. 4.—Diagram showing the effect of different applications of manure to irrigated soils on the distribution of moisture in the fall to a depth of 6 feet. Average of three years.

moisture occurred at the same depths as in the unmanured soil, but the eighth instead of the tenth foot had least.

The cropped manured plots showed the moisture to decrease rapidly from the surface to the sixth foot, after which it increased until at the tenth foot in the 5-ton plot there was more moisture than at any other depth. The unmanured plot showed a much higher average moisture content than the 5-ton plot and about the same as the one that received the 15 tons. The variation between the moisture in cropped and fallow soils was greatest in the 5-ton plot and least in the unmanured, the greatest differences occurring in the fifth, sixth, and seventh feet in the manured, and in the top few feet of the unmanured plots.

At the seventh and ninth feet of the unmanured plots, the cropped soil had more moisture than the fallow, while on the manured plots the cropped exceeded the fallow in the eighth, ninth, and tenth feet. Manuring did not have as marked an effect on the moisture in the fallow soil as it did in the cropped.

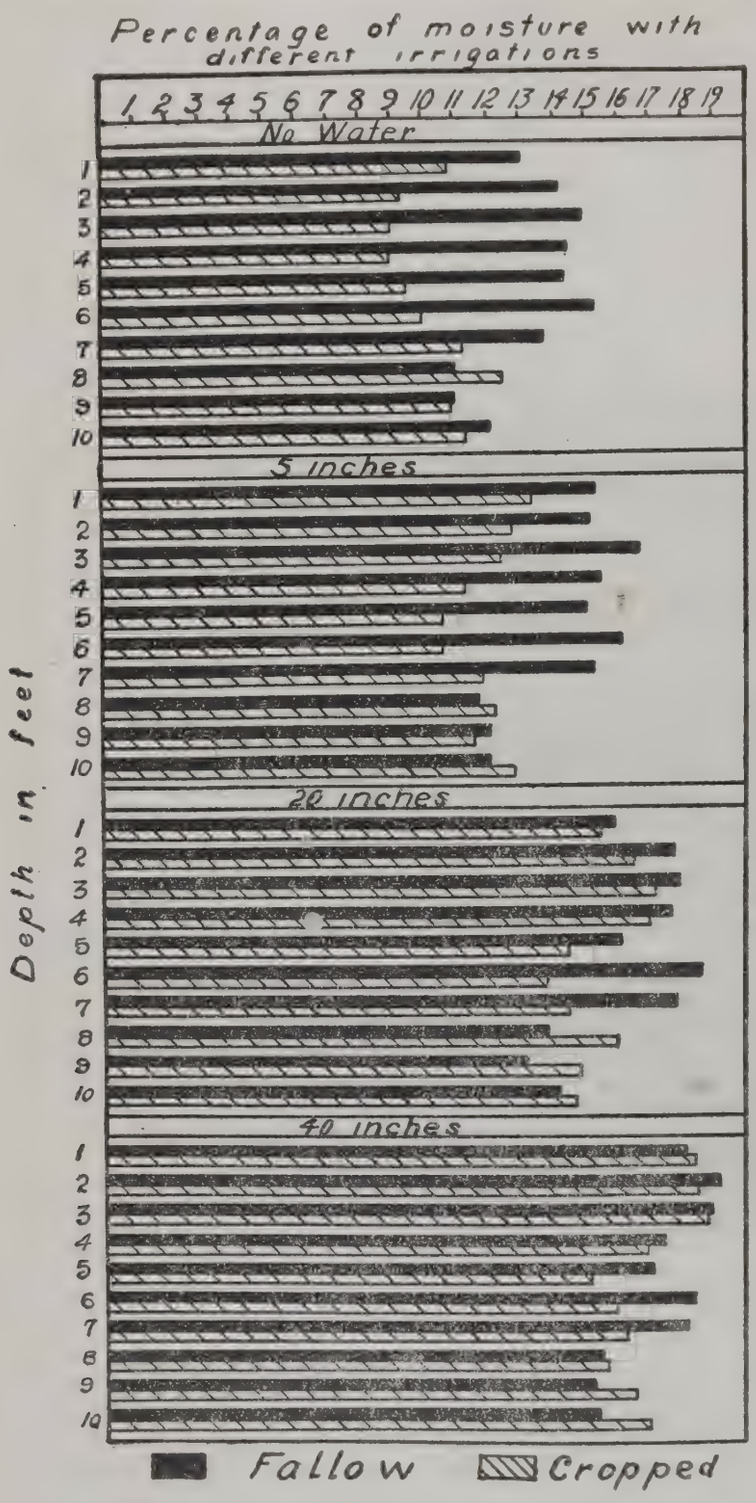
Percentage of moisture with different irrigations
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
No Water
5 inches
20 inches
40 inches
Depth in feet
1 2 3 4 5 6 7 8 9 10
Fallow
Cropped

FIG. 5.—Diagram showing the effect of different quantities of irrigation water on the distribution of soil moisture in the fall on cropped and fallow plots to a depth of 10 feet. Average of three years.

EFFECT OF DIFFERENT QUANTITIES OF IRRIGATION WATER

DISTRIBUTION IN THE FALL

The data for this test on the effect of different quantities of irrigation water on the soil moisture are from the experiment on cropping and fallowing under irrigation conditions.

In figure 5 is shown the fall distribution of moisture after no irrigation and the application of 5, 20, and 40 inches of water in cropped and fallow plots to a depth of 10 feet. From the figure it will be noticed that the moisture in both the fallow and cropped soils increased with increased irrigation, and that the difference between the moisture in the fallow and the cropped soil decreased with the increase in irrigation.

Where no water was applied, the moisture in the cropped plots decreased with depth to the fourth foot and then increased. In the cropped

plots receiving 5 inches of water this increase began after the sixth foot, while in those receiving 20 and 40 inches there was an increase in moisture from the surface to the third foot, then a decrease until the sixth foot, before the rise.

The fallow plots showed no marked variation in the percentage of moisture of the first 7 feet, but there was a sudden decrease from the seventh to the eighth, ninth, and tenth feet for all quantities of irrigation water.

The third and sixth feet in the fallow plots were highest in moisture for all irrigations.

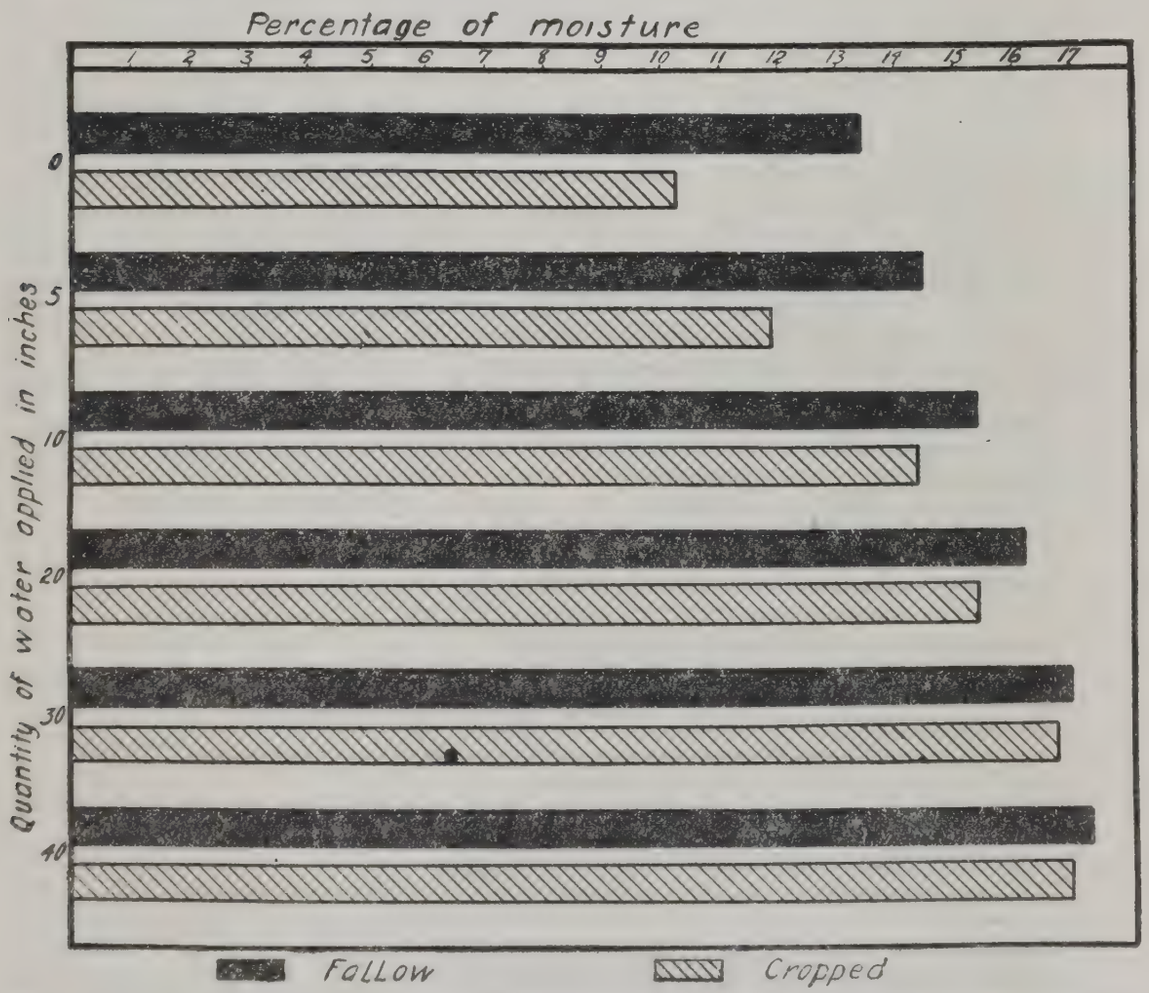

FIG. 6.—Diagram showing the effect of different quantities of irrigation water on the average final water content in 10 feet of soil in the fall in cropped and fallow plots. Average of three years.

The great variation in the moisture of the cropped soils receiving small applications of water was, of course, due to the withdrawal of moisture from the upper few feet by the crop. This loss is much less noticeable in the heavily irrigated soils.

Figure 6, derived from the same data as figure 5, shows the variation in the moisture content of the first 10 feet of cropped and fallow plots receiving different quantities of water.

That the first 5 inches of irrigation produced the greatest increase of moisture, and that each successive increase of 10 inches of water produced smaller increases in the moisture content of both cropped and

fallow plots is made clear by the graph. The difference between the moisture in cropped and fallow soils decreased with the larger applications of water.

Distribution One Week After Irrigation in Beet and Potato Plots

These data were secured from the unmanured plots 41 F to 45 F and 61 F to 65 F on the Greenville Farm during 1912 and 1913. Plots 41 F to 44 F and 61 F to 64 F were irrigated weekly with applications of 1, 2½, 5, and 7½ inches, respectively, while 45 F and 65 F were unirrigated. Samples of the soil were taken immediately before irrigation and 24 hours after, each plot being sampled in three places to eliminate possible inequality in the distribution of the moisture.

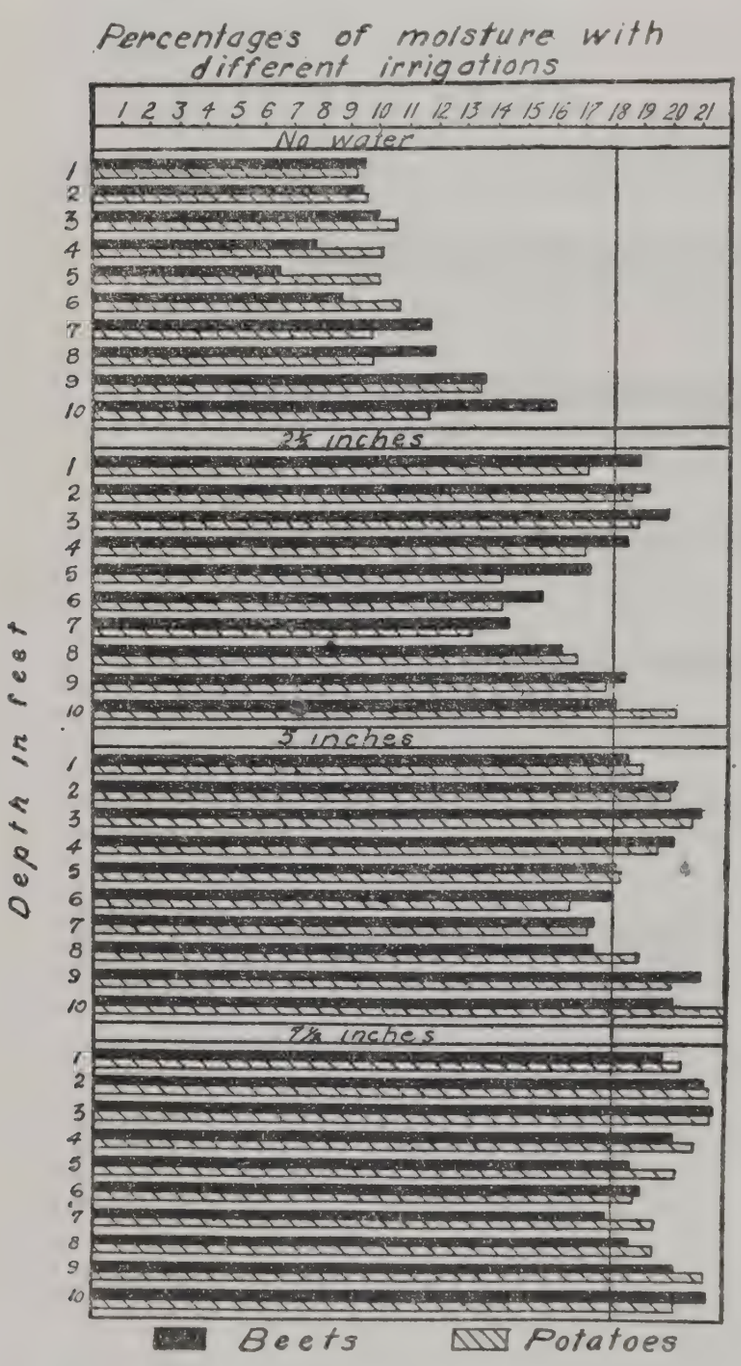
Percentages of moisture with different irrigations
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
No water
2½ inches
5 inches
7½ inches
Depth in feet
Beets
Potatoes

Fig. 7.—Diagram showing the effect of different quantities of irrigation water on the distribution of moisture one week after irrigation in beet and potato plots to a depth of 10 feet. Average of two years

Plots 41 F to 45 F were cropped with potatoes, while 61 F to 65 F were in sugar beets.

Figure 7 gives the 2-year average moisture content one week after the irrigation of the beet and potato plots. Increased irrigations are shown to have increased the moisture content, but the first 2½ inches of water produce by far the greatest proportionate gain, especially on the upper soil layers. With the exception of the moisture in the potato plots receiving no irrigation, there was a marked tendency for the water to accumulate in the second, third, fourth, ninth, and tenth feet, with a depression at medium depths.

The difference between the moisture in the beet and the potato soil was not great except in the plots receiving no water and 2½ inches. Beets drew heavily on the water of the fourth, fifth, and sixth feet, while potatoes took more from the lower depths of the unirrigated soil. In nearly all depths for the 2½-inch irrigation the potatoes used more water than did the beets.

Distribution Before and After Irrigation

Figure 8, showing the distribution of moisture immediately before and 24 hours after irrigation of 1, 2½, 5, and 7½ inches, was taken from plots 41 F to 45 F and 61 F to 65 F, described in the above experiment. The results are averages of several tests in 1912 and 1913.

This graph strikingly indicates the rapidity of moisture movements. With a slight exception in the case of the 2½-inch watering, there was an appreciable increase in the soil moisture to a considerable depth within 24 hours after the application of from 1 to 7½ inches of water. Most of the moisture, however, was retained in the first 4 feet, below which there was an irregular decrease with depth.

Before and after irrigation the water in the soil tended to accumulate in the first 3 and the last 3 feet. This distribution is most evident where small irrigations were given, for with the larger applications the moisture tended to decrease irregularly with depth.

Effect of Mulches

Under Irrigation

This was a study on the Greenville Farm in 1913 of a fallow plot receiving different cultural treatments. On June 12 and on August 7 and 27, 5-inch applications of irrigation water were given the soil. The plot was divided into three equal parts; one part was left unmulched with the weeds pulled, another received a 2-inch straw mulch, and the third was cultivated 2 inches deep.

Samples of the soil were taken on July 16, August 8, 15, 22, 28, and September 10, 1913. Figure 9 shows the distribution of moisture under the different mulches as found by averaging all these samplings. It will be noticed that the moisture under all treatments increased from the surface down to the third foot, after which there was a decrease to the ninth foot.

The 2-inch straw mulch showed the highest percentage of water for all depths except the tenth foot, while the unmulched soil with weeds pulled had the least moisture, except in the eighth foot. There was about the same difference between the 2-inch straw mulch and the 2-inch cultivation as there was between the latter and unmulched soil, at least in the upper soil layers. The lower depths showed less difference.

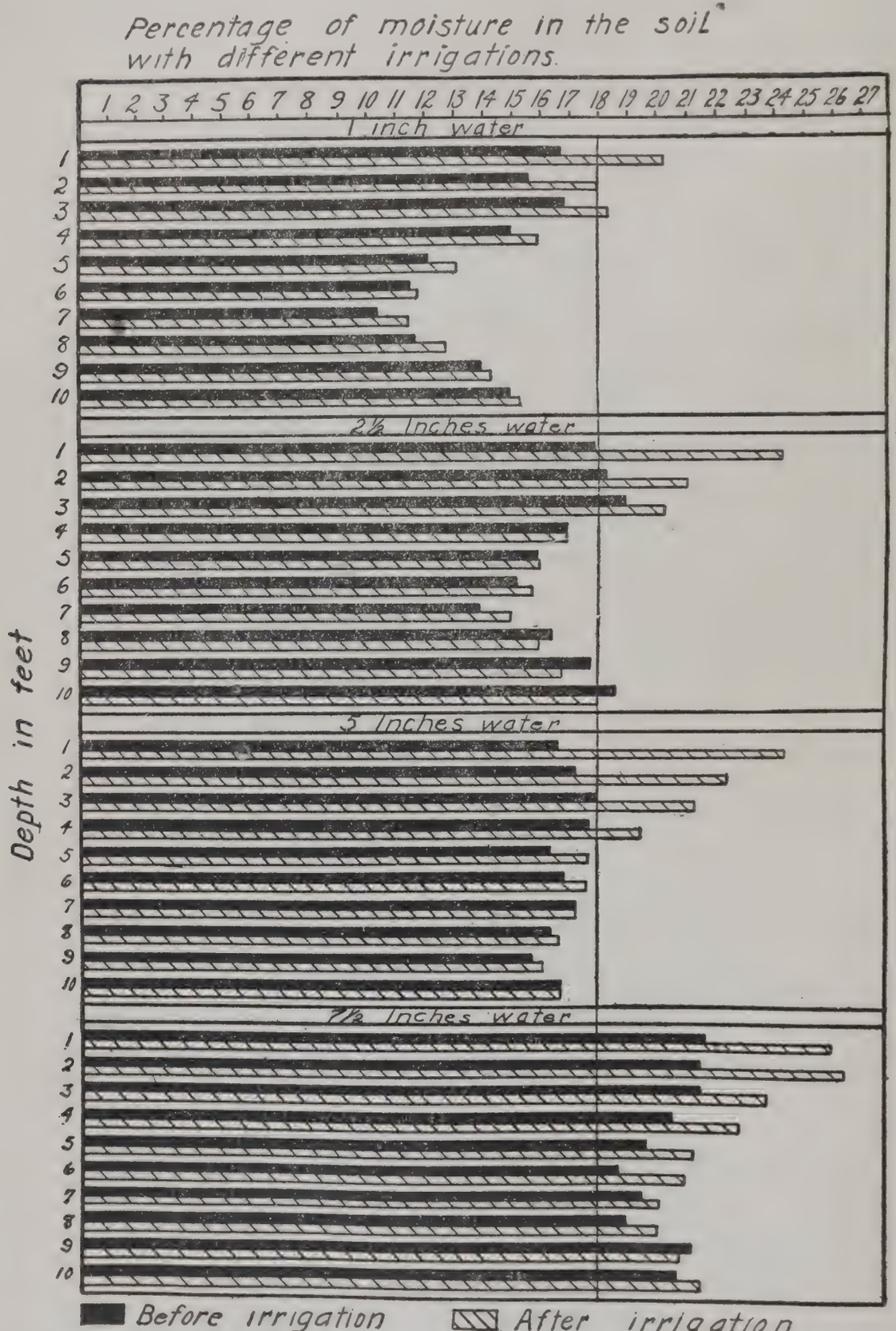
Percentage of moisture in the soil with different irrigations.
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27
1 inch water
2½ Inches water
5 Inches water
7½ Inches water
Depth in feet
Before irrigation
After irrigation

FIG. 8.—Diagram showing the effect of different quantities of irrigation water on the distribution of moisture before and after irrigation to a depth of 10 feet. Average of two years.

UNDER DRY-FARMING

The mulch experiments at the Nephi Substation were made as follows: A duplicate series of one-tenth-acre plots was selected, each series including 12 different treatments. These two series of plots, which had previously been in wheat, were treated as shown in Table I.

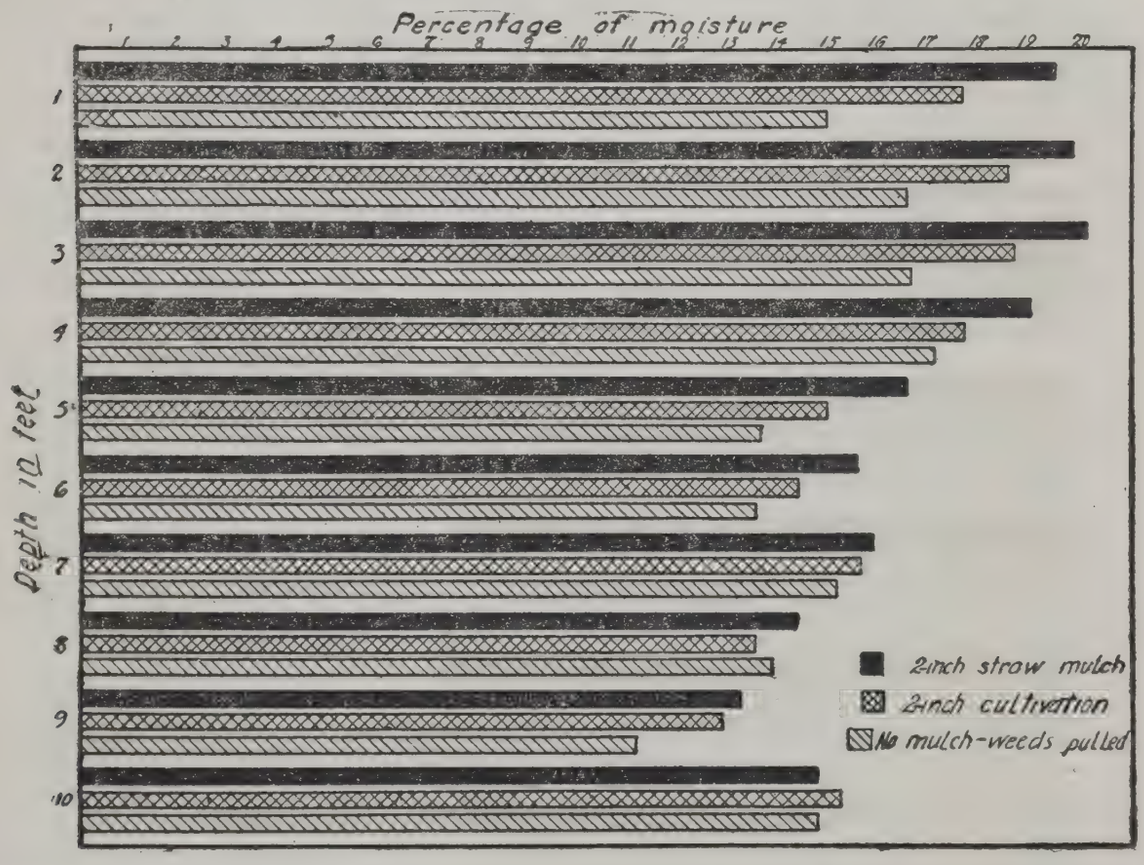

FIG. 9.—Diagram showing the effect of mulches under irrigation on the distribution of soil moisture to a depth of 10 feet.

TABLE I.—*Treatment of duplicate series of one-tenth-acre plots previously in wheat at Nephi Substation*

Plot.		Treatment.
Series A.	Series B.	
0	11	Never plowed; weeds pulled or hoed.
1	10	Fall-plowed; straw mulch.
2	9	Fall-plowed and subsoiled (18 inches); mulched, 4 inches.
3	8	Fall-plowed; disked once in spring.
4	7	Fall-plowed; weeds pulled.
5	6	Fall-plowed; mulched 2 inches.
6	5	Fall-plowed; mulched 4 inches.
7	4	Fall-plowed; mulched 6 inches.
8	3	Spring-plowed; weeds pulled.
9	2	Spring-plowed; mulched 2 inches.
10	1	Spring-plowed; mulched 4 inches.
11	0	Spring-plowed; mulched 6 inches.

In order to maintain the earth mulches according to the plan, the plots were harrowed with a spike-tooth harrow as soon after a rain as convenient and at such times as the land seemed to warrant harrowing. The plots were kept as free from weeds as possible by hoeing whenever weeds appeared.

In order to find the fluctuation in the moisture content, the plots were sampled as frequently as the determinations could be made—about every 10 days. The samples were taken in foot sections with a 6-foot King tube and immediately placed in sample cans provided with tight-fitting lids. For every determination each plot was sampled in duplicate, one sample being taken a fourth of the way from the east side of the plot and the other at a corresponding distance from the west side.

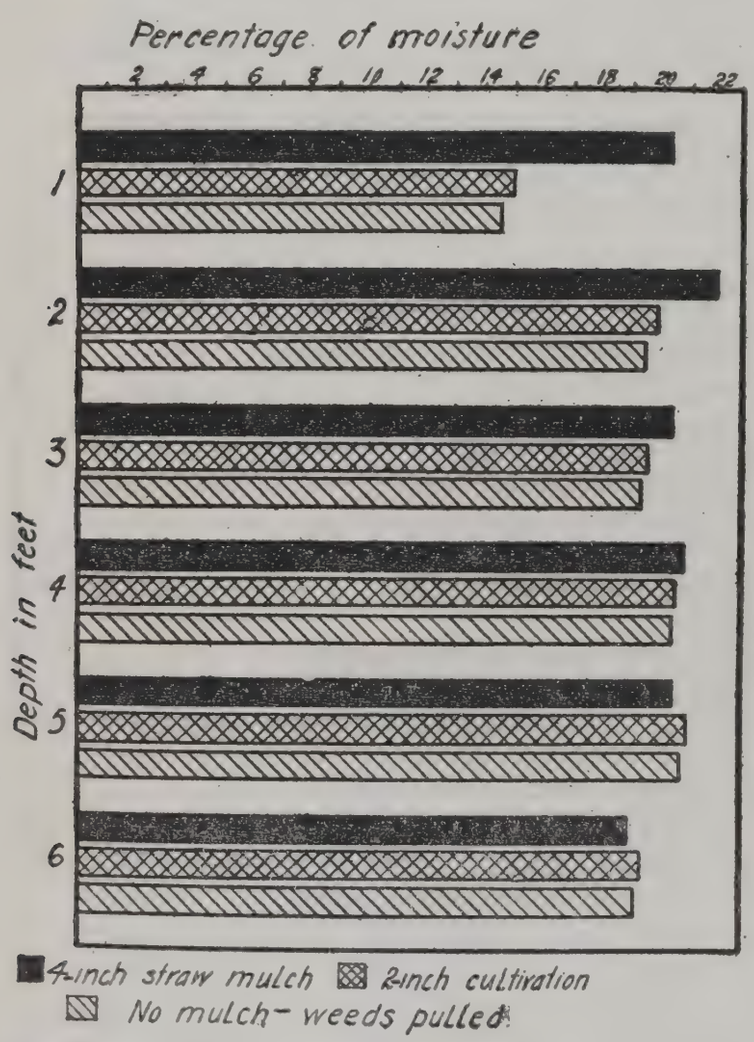

FIG. 10.—Diagram showing the effect of mulches under dry-farming conditions on the average distribution of soil moisture to a depth of 6 feet.

The plots were sampled between May 22 and 29, June 6 and 10, June 16 and 19, June 26 and 29, July 12 and 15, July 17 and 19, July 27 and 29, August 7 and 9, August 17 and 19, and August 28 and 30, 1916. In all, 2,880 samples were taken.

In figure 10, which gives the average per centage of moisture from the season's work, the most striking point shown is that the effect of mulches under dry-farm conditions is not apparent below the third foot. The straw mulch was much more efficient in preserving the moisture of the top feet than the 2-inch cultivation; in fact, the latter is hardly better than no mulch.

EFFECT OF CULTURAL METHODS

CULTURAL EXPERIMENTS AT NEPHI IN 1916

The data for this discussion were taken from the experiment on the effect of mulches under dry-farming conditions. In figure 11 are pre-

sented the averages of the 10 samplings for each of the first 6 feet throughout the season of 1916. Each column is the average of 240 samples.

The 4-inch straw mulch on the fall-plowed land prevented moisture loss better than other treatments, while the plot that was not plowed but had the weeds pulled was next in efficiency. Disking fall-plowed land once in the spring and cultivating spring-plowed land 6 inches deep proved to be the best cultural methods under fall and spring plowing, respectively.

The efficiency of spring-plowed plots in moisture conservation increased with the increased depth of cultivation, while in the fall-plowed plots the reverse is indicated. Since even the uncultivated soils maintained an average moisture content of about 19 per cent throughout the season, the importance of cultivation on land kept free from weeds was not so great for this year as might have been expected.

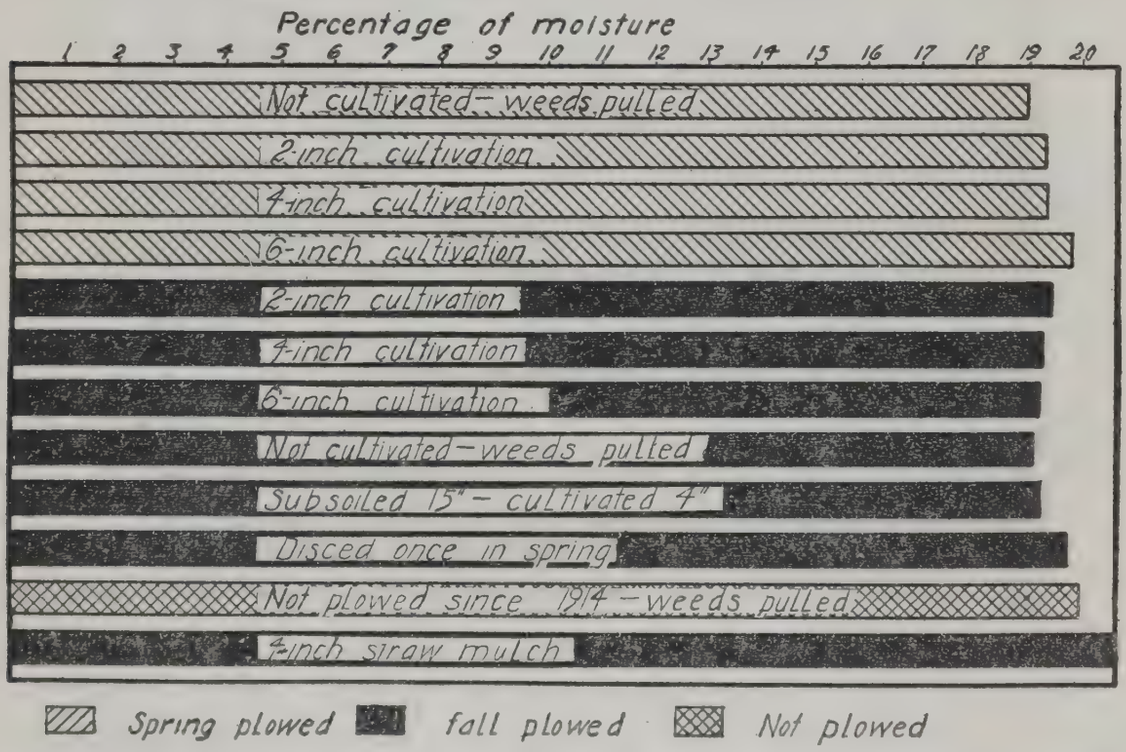

FIG. 11.—Diagram showing the effect of cultural methods under dry-farming conditions on theav erage final content of moisture in the soil to a depth of 6 feet. Each column is an average of 240 samplings.

CULTURAL EXPERIMENTS AT NEPHI BETWEEN 1909 AND 1916

This cultural experiment at the Nephi Substation was conducted during the eight years from 1909 to 1916, inclusive. All spring- and all fall-plowed fallow plots were sampled in duplicate to a depth of 6 feet in the spring, the summer, and the fall.

From figure 12 a rather pronounced difference is seen between the distribution in the fall- and spring-plowed plots. In the former the top foot had the least moisture and the second foot the most, with a decline from this to the fifth foot. The spring-plowed plots, on the other hand, showed an increase downward from the surface to the fourth foot before the decline began. Except in the first and second feet in the spring, the spring-plowed plots had more moisture than the fall-plowed ones. This difference in favor of spring plowing was most marked in the third, fourth, and fifth feet. It would seem from this that fall-plowed soils tend to hold

the moisture in the upper 2 feet and prevent its rapid descent into the lower soil layers. This allows much of the moisture to be lost by evaporation; hence, the lower layers remain drier than the corresponding layers of spring-plowed soil.

EFFECT OF PRECIPITATION

The data presented in figure 13, showing the effect of the season on the distribution of soil moisture, were obtained from the experiment on the

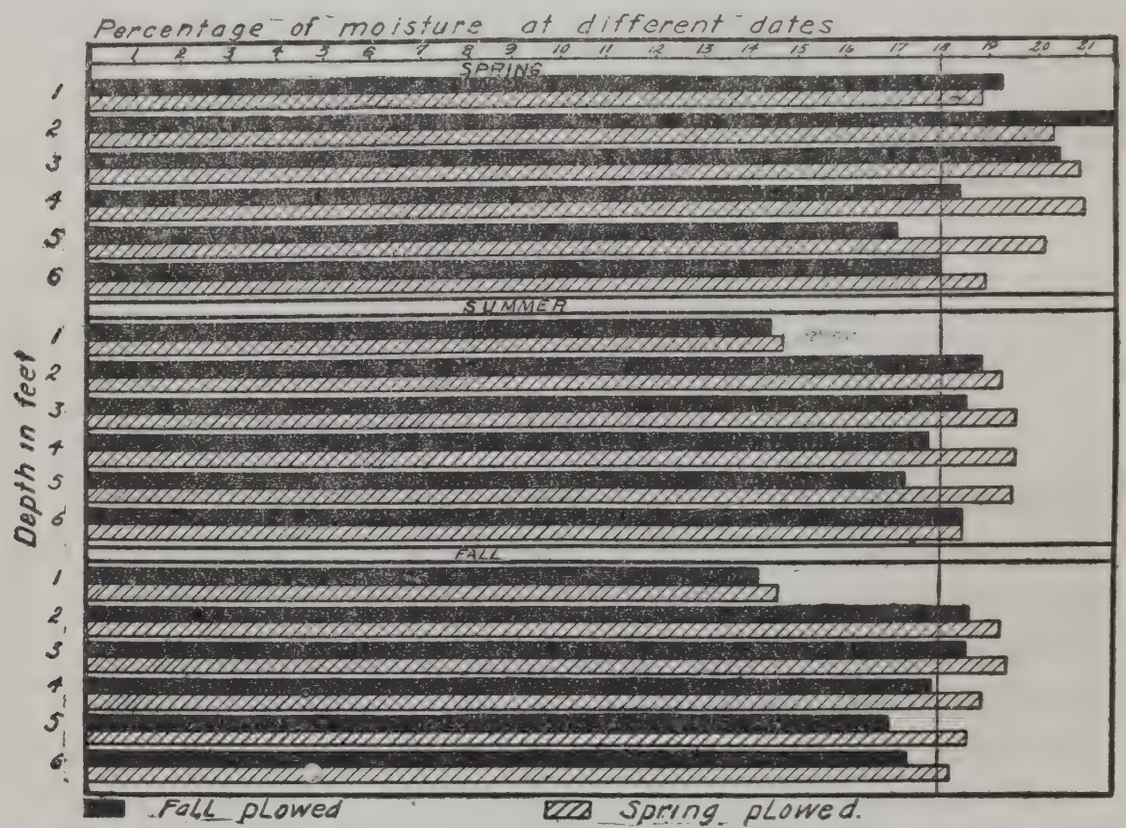

FIG. 12.—Diagram showing the effect of spring and fall plowing under dry-farming conditions on the distribution of moisture in the spring, summer, and fall to a depth of 6 feet. Average of eight years.

effect of mulches under dry-farming conditions at Nephi presented in figures 10 and 11.

Each column in the figure is the average of the moisture in the 24 plots receiving the 12 treatments described in the above experiment.

The rainfall throughout this period is in Table II.

TABLE II.—*Rainfall (in inches) at Nephi Substation from May 19 to August 16, 1916, inclusive*[a]

Date.	Rainfall.	Date.	Rainfall.	Date.	Rainfall.
May 19	0.74	July 8	0.07	Aug. 3	0.38
May 20	.22	July 10	.22	Aug. 5	.26
		July 17	.20	Aug. 7	.04
		July 24	.08	Aug. 16	.10
		July 25	.16		
		July 26	.11		
		July 27	.30		
Total	.96	Total	1.14	Total	.78

[a] There was no precipitation in June.

Figure 13 shows that in all depths the moisture decreased from May 22 to 29 to July 12 to 15, after which it increased because of the rainfall prior to the samplings on July 27 to 29 and August 7 to 9. It will be noticed, however, that precipitations as small as 0.10 of an inch in early July and middle August did not affect the moisture content of even the first foot. From these dates until August 28 to 30 the percentage of moisture decreased. The variations mentioned were very marked in the first foot and, although there is a similar fluctuation in every foot, a decrease with increase in depth is noticed until at the sixth foot the influence of the season was very slight. Evidently a loss or a gain in the surface foot very soon disturbed the moisture equilibrium to a depth of 6 feet, due to the action of capillarity.

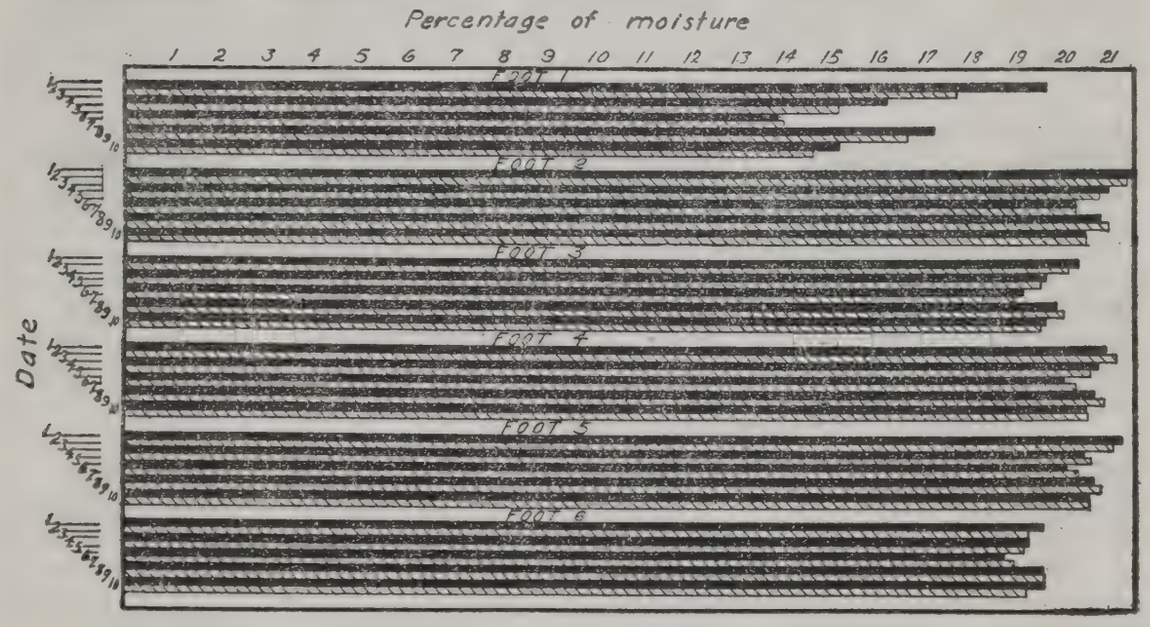

FIG. 13.—Diagram showing the effect of dry-farming seasonal conditions on the distribution of moisture in fallow soil to a depth of 6 feet on (1) May 22–29, (2) June 6–10, (3) June 16–20, (4) June 26–28, (5) July 12–15, (6) July 17–19, (7) July 27–29, (8) August 7–9, (9) August 17–19, (10) August 28–30, 1916. The numbers 1 to 10, etc., refer to the columns in the diagram, which were sampled on the dates noted. Each column is the average of 24 samplings.

LABORATORY STUDIES

EFFECT OF INITIAL PERCENTAGE OF SOIL MOISTURE

EFFECT ON UPWARD CAPILLARY MOVEMENT

In order to study the effect of the initial percentage of moisture in the soil on the upward capillary movement of water, jointed brass tubes 8 inches long and 1½ inches in diameter were filled with Greenville loam containing, respectively, 2½, 5, 10, 15, and 20 per cent of moisture. For each test, columns made by screwing together three of the brass tubes were used. These tubes were held upright in a few inches of water for periods of 24, 48, 72, and 120 hours, at the end of which they were taken down and the percentage of moisture determined for each 8-inch section.

In figure 14 the results of this experiment are recorded. The columns in the figure are in the positions the soils were in the experiment, the lowest one being in contact with the water.

With a few exceptions, every initial percentage in the figure indicates that for each successive 24-hour period after the first the moisture in the middle and top sections increased, while that of the section in contact with the moisture increased little during 120 hours. Although the moisture in the top sections was considerably less than the others after the first 24 hours, at the end of 120 hours there was a tendency for all three sections to contain the same percentage of moisture.

Soil having the lowest initial percentage of moisture showed the greatest variation between the section farthest from the source of moisture

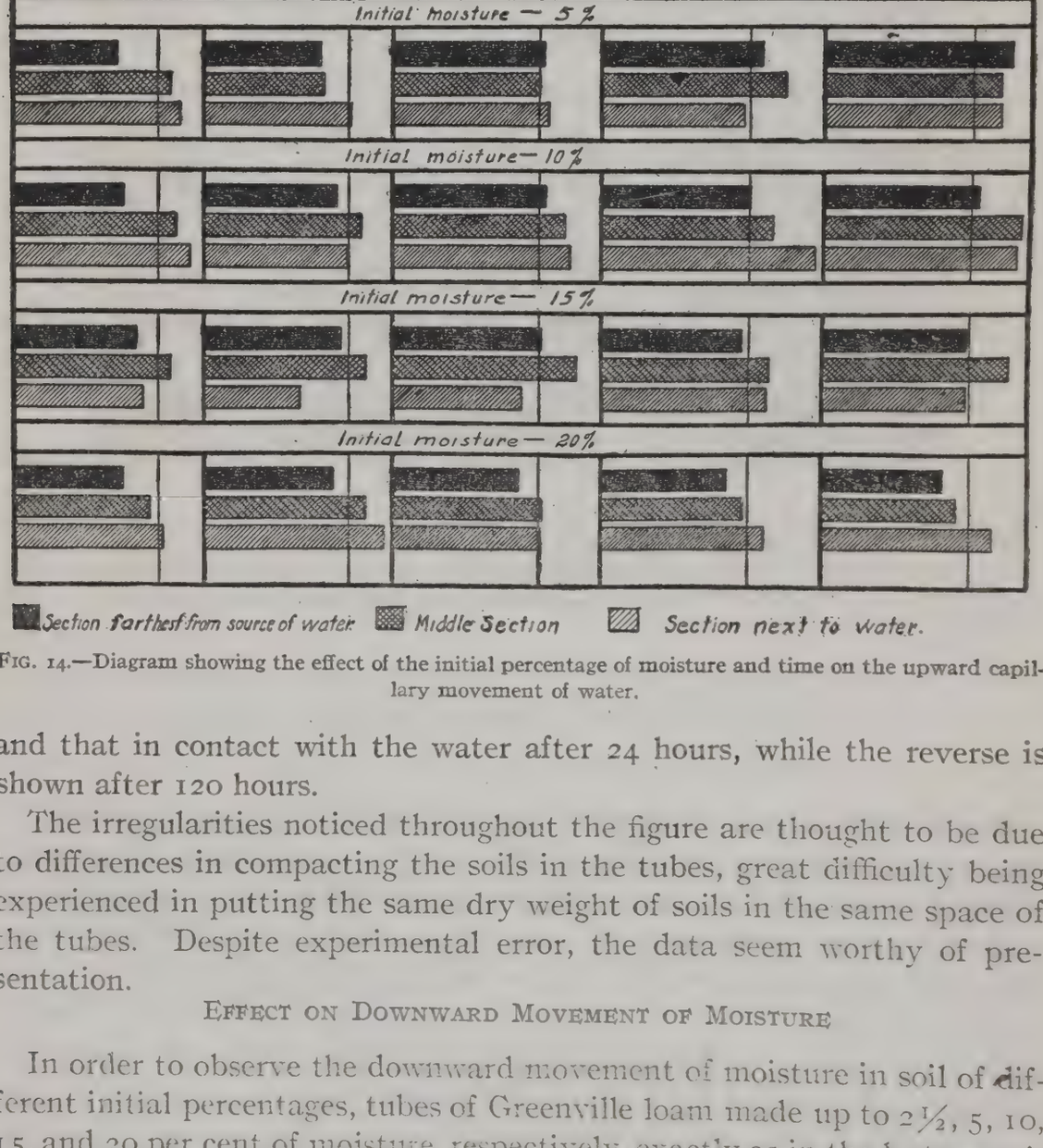
Percentage of moisture in soil after capillary rise for various periods.
24 Hrs.
48 Hrs.
72 Hrs.
96 Hrs.
120 Hrs.
Initial moisture — 2½ %
Initial moisture — 5 %
Initial moisture — 10 %
Initial moisture — 15 %
Initial moisture — 20 %
10 20 30 40
Section farthest from source of water
Middle Section
Section next to water.

FIG. 14.—Diagram showing the effect of the initial percentage of moisture and time on the upward capillary movement of water.

and that in contact with the water after 24 hours, while the reverse is shown after 120 hours.

The irregularities noticed throughout the figure are thought to be due to differences in compacting the soils in the tubes, great difficulty being experienced in putting the same dry weight of soils in the same space of the tubes. Despite experimental error, the data seem worthy of presentation.

EFFECT ON DOWNWARD MOVEMENT OF MOISTURE

In order to observe the downward movement of moisture in soil of different initial percentages, tubes of Greenville loam made up to 2½, 5, 10, 15, and 20 per cent of moisture, respectively, exactly as in the last experiment, were used. The water in this case, however, was applied to the

top sections in quantities corresponding to irrigations of 5, 8.66, and 15 inches. Surface evaporation was prevented by covering the open ends. To determine the moisture in the different sections, the sets were taken down 1, 2, 3, 5, and 10 days after the application of water.

These results are recorded in figures 15 and 16. It will be noticed from figure 15 that during the 10 days after the application of an 8.66-inch irrigation a considerable amount of moisture was drawn from the section receiving the water into the lower sections for every initial percentage. The two lower sections of the soil with 2½ per cent of moisture and the sixth section of the 5 per cent soil had not been changed after standing 10 days. The most rapid downward movement, as indicated by

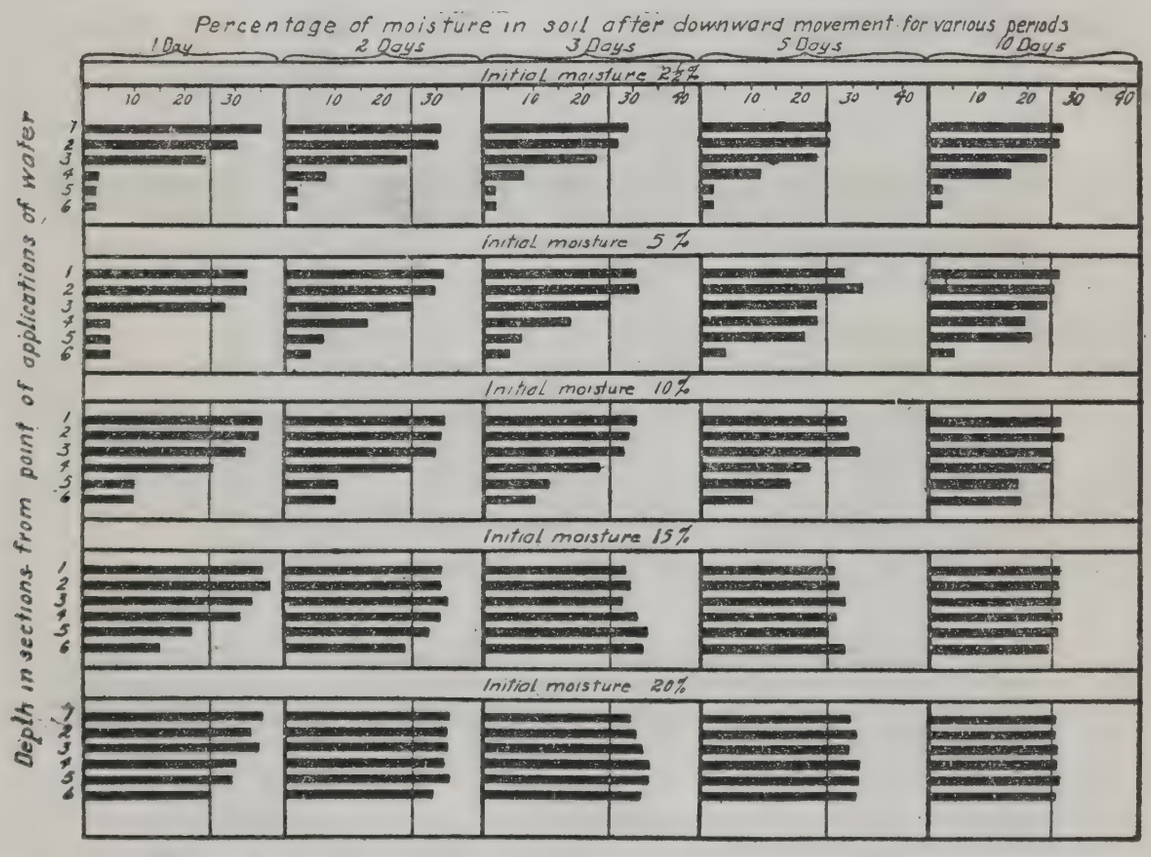

FIG. 15.—Diagram showing the effect of the initial percentage of moisture and time on the downward movement of water after an 8.66-inch irrigation.

the increase in moisture in the lower sections, is found in the soil having the greatest initial moisture content.

The figure shows practically no difference in the percentage of water in the soils with a high initial percentage of moisture after 10 days, but there was a marked difference in the drier columns of soil.

In figure 16 is presented the average distribution of moisture in the first 10 days after irrigation. It will be noticed from the figure that with an increase in initial percentage above 5 per cent there was a very rapid increase in the depth of penetration, the increase being most marked in the columns receiving the largest application of water.

In the drier soils the larger irrigation increased the moisture of the top sections more than the smaller, but the difference was not so noticeable in the soils having a 20 per cent initial content. This can readily be

accounted for by assuming that the large application of water to the already wet soil would more than satisfy the capillary demand of the soil, and consequently the excess water would penetrate rapidly downward, leaving the two surfaces equally moist. In all initial percentages and for all irrigations the moisture content decreased with depth from the point of application of the water.

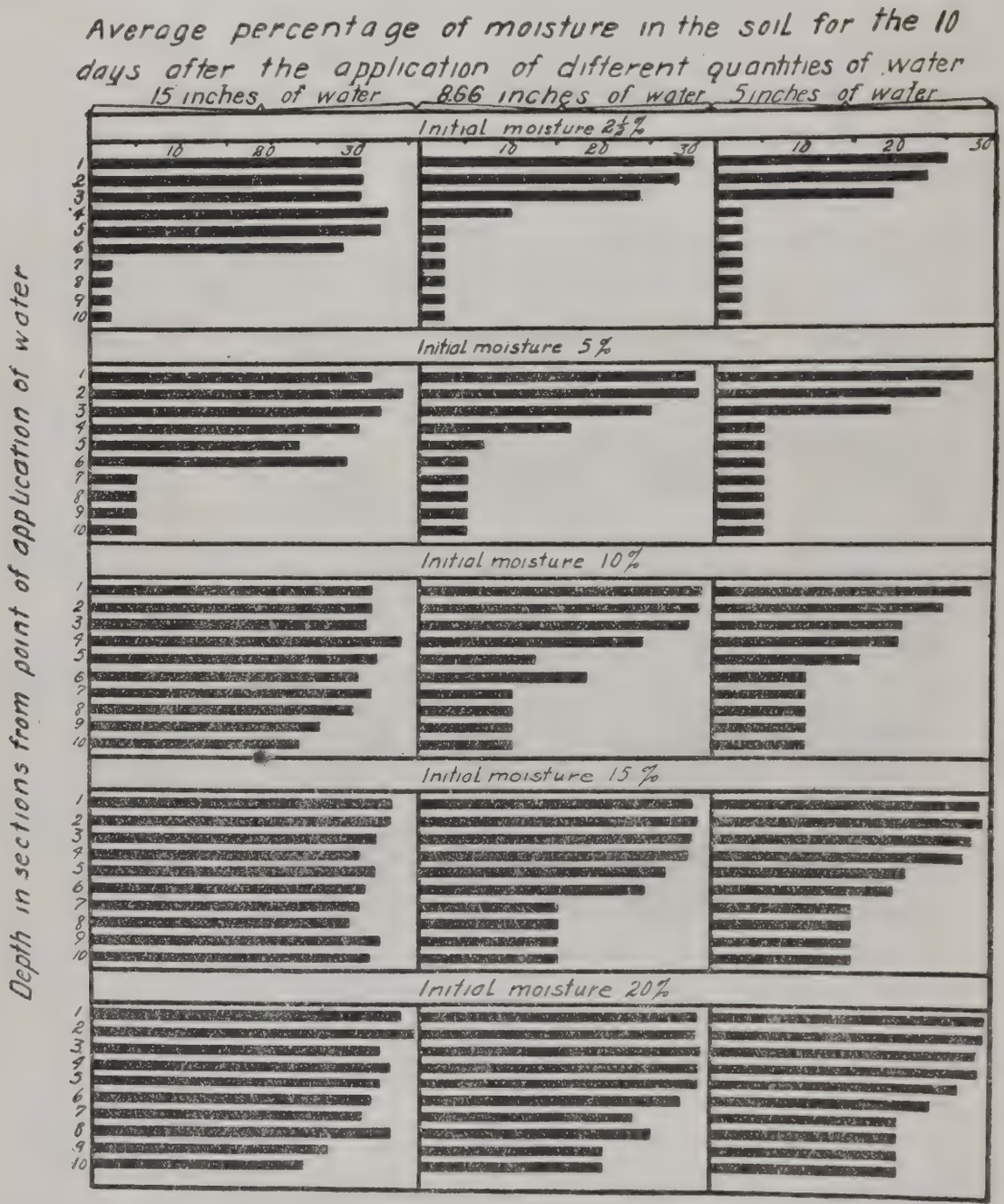

FIG. 16.—Diagram showing the effect of the initial percentage of moisture on the downward distribution of moisture in soils after the application of varying quantities of irrigation water.

EFFECT ON THE HORIZONTAL DISTRIBUTION OF MOISTURE

DETERMINED BY WEIGHING ONE END OF A COLUMN OF SOIL

Ten brass tubes similar to those previously described were filled with Greenville loam containing 24.36 per cent of moisture, the soil being compacted by pressing layers of equal thickness into the tubes. Similar

tubes were then filled in duplicate with the soil containing 3.65, 5.30, 6.52, and 8.24 per cent of moisture.

The wet and dry sets of tubes were then brought into contact with each other by means of collars, a good contact being secured by bulging the soil in each tube slightly above the top. The open ends of the tubes were then made air-tight by sealing with corks that had been dipped in paraffin. In this manner an 8-inch column of wet soil was in contact with an 8-inch column of drier soil. In order to study the movement of water in these soils, a loop was attached to the corks at each end of the tube, care being taken that each loop was equidistant from the center of the tube. The tubes were then suspended horizontally from hooks

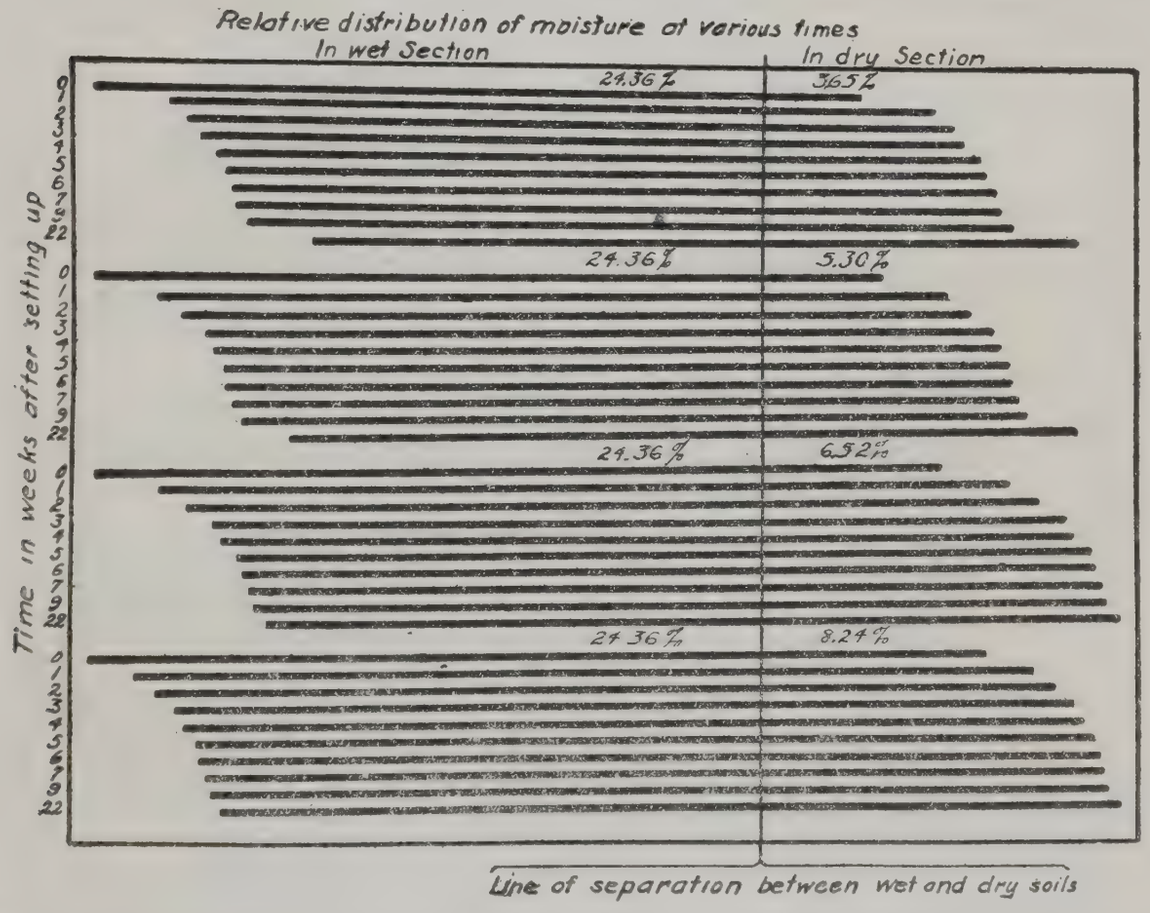

FIG. 17.—Diagram showing the effect of varying initial percentages of water on the horizontal distribution of moisture in drier soils in contact with a wet soil having 24.36 per cent of water. The top line of each series represents the original distribution.

by the loop at the wet ends, while the loops at the drier ends of the columns were attached to one arm of a balance.

As moisture moved from the wet into the drier soil the equilibrium of the balance was disturbed and more weights were added. The weights added at the end of each week were recorded during the period from March 22 to September 6, 1916.

The results of the experiments are found in figure 17, which shows the relative loss in the wet and the corresponding gain in the drier soil at the end of weekly intervals.

It will be noticed that during the first two weeks the soil that was wettest at the beginning gained less water than the others. From the

third week to the twenty-second the gain in the dry soils decreased as the initial percentage increased, although for the first three weeks the soil with 6.52 per cent of moisture gained most and that with an initial percentage of 8.24 gained the least water. In the soil having 8.24 per cent there was hardly any appreciable gain after the sixth week. It is probable that on account of the greater ease with which the moisture moves through the moist soil such soil has its capillary demands satisfied before the drier one, and consequently movement takes place for a longer time in the drier soil.

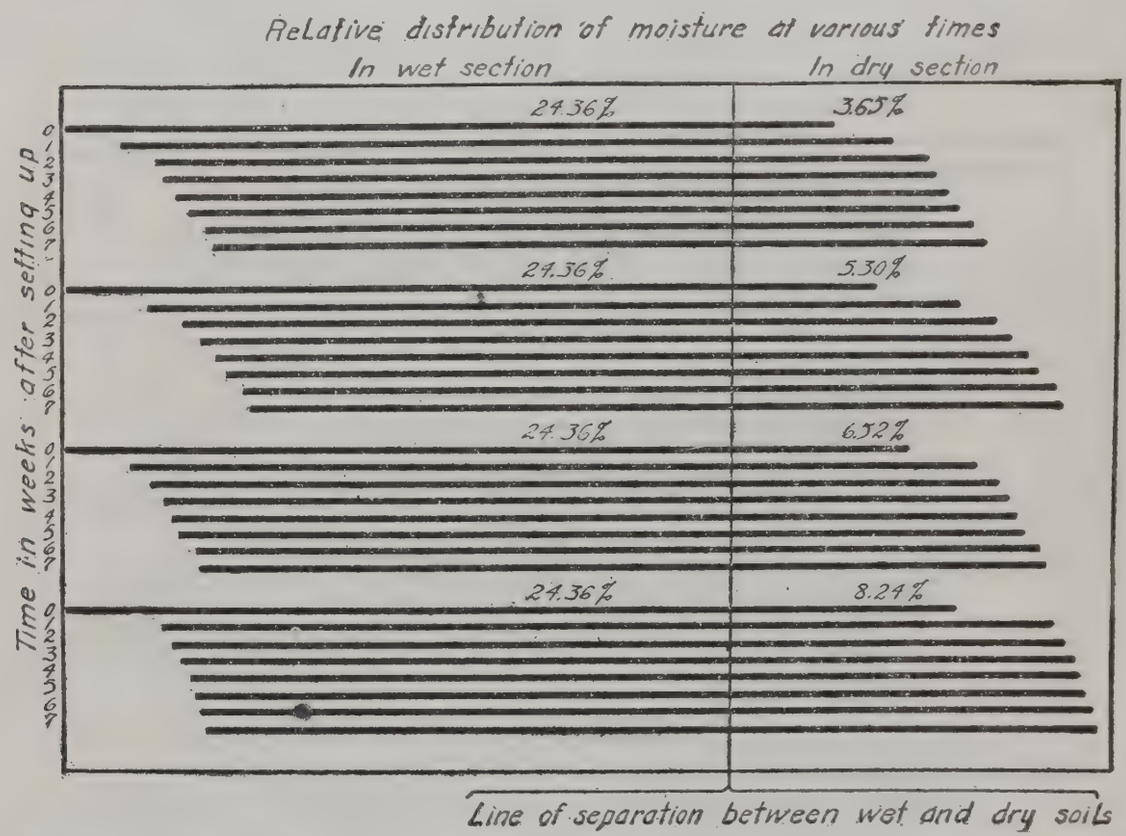

FIG. 18.—Diagram showing the effect of varying initial percentages of water on the horizonal distribution of moisture in drier soils in contact with a wet soil having 24.36 per cent of water. The top line of each series represents the original distribution.

DETERMINED BY THE DEFLECTION OF ONE END OF A LARGE SOIL COLUMN

In this study the moist soil was placed in 6-inch glass tubes having diameters of ¾ inch. The wet soil in the one tube was held in contact with the drier soil in the other by connecting the tubes with celluloid. The soil used and the moisture contents for the standard wet soil and the drier soil were exactly the same as in the last experiment.

The columns formed by the tubes of wet and dry soils in contact were suspended from their centers by pieces of string and were then brought into an exactly horizontal position by adding weights to the lighter ends. A pin was then attached to the end of the tube containing the moist soil, so that as the moisture moved into the drier soil the moist end swung up and scratched the paraffined surface of a glass plate. Records of these scratches were made weekly throughout the experiment, which lasted from March 21 to May 8, 1916.

Figure 18 represents the relative weekly losses in the wet soils and gains in the drier soils of this experiment. During the first week the gain increased with the increased initial percentage, but thereafter the reverse was true, very little gain taking place in the soil having 8.24 per cent of water after the first week.

DETERMINED BY THE DEFLECTION OF ONE END OF A SMALL COLUMN OF SOIL

This experiment is essentially a duplication of the last one except that 6-inch test tubes were used instead of 8-inch colorimeter tubes and that

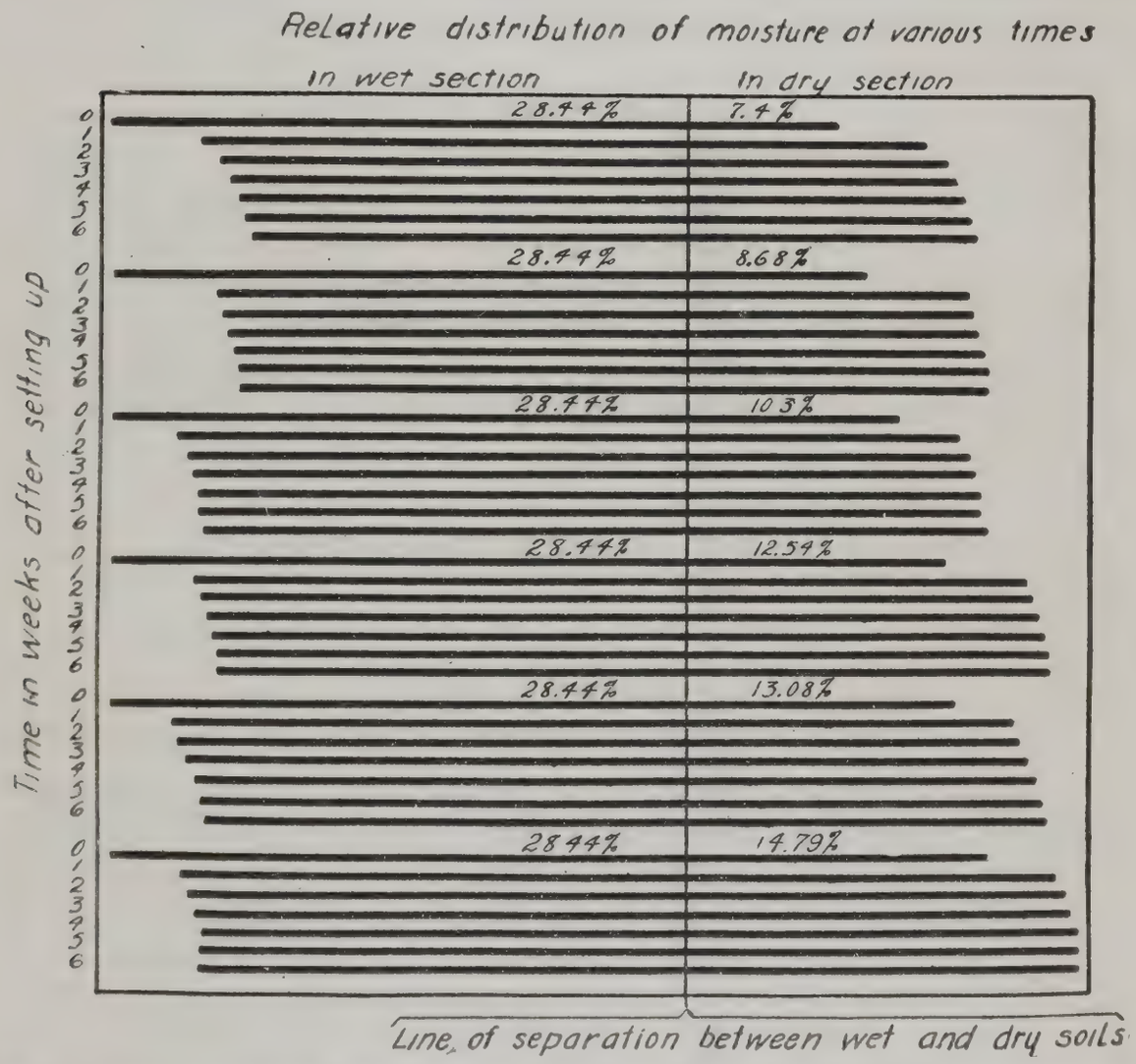

FIG. 19.—Diagram showing the effect of varying initial percentages of water on the horizontal distribution of moisture in drier soils in contact with a wet soil having 28.44 per cent of water. The top line of each series represents the original distribution.

the standard wet soil contained 28.44 per cent of moisture, while the drier soils had 7.40, 8.68, 10.30, 12.54, 13.08, and 14.79 per cent of water, respectively. This test lasted from April 5 to May 22, 1916, the record being made as in the previous experiment.

In figure 19 are given the relative weekly losses in the wet and gains in the drier soils. Although the soils with initial percentages of 8.68 and 12.54 are exceptions, the gain in weight for the first week decreased with an increase in the initial percentage. After the first week the gain decreased more uniformly with the increasing initial percentage.

As a whole, then, figures 17, 18, and 19 indicate that water is gained most rapidly during the first week by soils having about 8 per cent of moisture. After the first week the gain increased uniformly with decrease in initial percentage.

The relatively small decrease in the attractive force for water with an increase in initial content up to 8 per cent, together with the greater ease with which moisture moves through the soil with an increase in water content, allows the maximum movement in the first week in the soil having 8.24 per cent. The slight gain in weight even for the first week in the soils with more than 8 per cent of moisture seems to indicate a marked decrease in the attractive force for water above this point.

That this is true seems to be shown, because after the first week, when the moisture content had risen somewhat, hardly any appreciable gain was observed. In the soils having less than 8 per cent the resistance of the dry soil to moisture movement prevented an equilibrium from being established as soon as in the wetter ones. Consequently a considerable movement will take place in the dry soil after the wet one has apparently come to rest. It must be kept in mind that the source of water was an unsaturated soil which itself has great water-holding power, as pointed out by Briggs and McLane (6) and Bouyoucos (3). With every loss of moisture from the source into the drier soil there is a stronger resistance to the movement in the wet soil. Only soils with a very great attractive force for water can draw water out of such a soil for any length of time.

Effect on Distribution with a Large Amount of Unsaturated Soil as the Source of Moisture Supply

In the fourth experiment on the effect of initial percentage on the movement of soil moisture, columns of soil formed by filling eight sets of brass tubes of three sections each with Greenville loam having 1.49, 3.27, 4.83, 10.21, 12.44, and 14.20 initial percentages were inserted to a depth of about 4 inches into Greenville loam containing 30.45 per cent of water. This wet soil was held in a moisture-proof wooden tub. The tubes of soil were inserted horizontally through eight holes bored in the sides of the tub. The apparatus presented the appearance of a wheel with the hub as the source of moisture. The open ends of the tubes and the top of the tub were carefully sealed to prevent all loss of water by evaporation. The experiment lasted from May 24 until September 12, 1916, when the tubes were removed and the moisture determined for each 2-inch section of the eight 24-inch tubes.

Figure 20 gives the average moisture content for each of the eight columns of soil. Scarcely more than a 2 per cent difference is found between the highest and lowest moisture contents. The column of soil originally having 4.83 per cent of moisture absorbed the most water, while that with an initial percentage of 10.21 had the least.

The graph indicates that, where a soil is given sufficient time in contact with a larger quantity of unsaturated soil, the initial percentage of moisture has no effect on the final moisture content.

It is quite probable that the small fluctuations shown in the figure were produced by variations in the compactness of the soil in the tubes, for it is very difficult to get the same amount of dry and wet soil in the same space without compacting them differently. That this is the explanation is supported by the fact that the tubes containing soil with initial percentages of 4.83 and 10.31 contained, respectively, 703 and 603 gm. of dry soil.

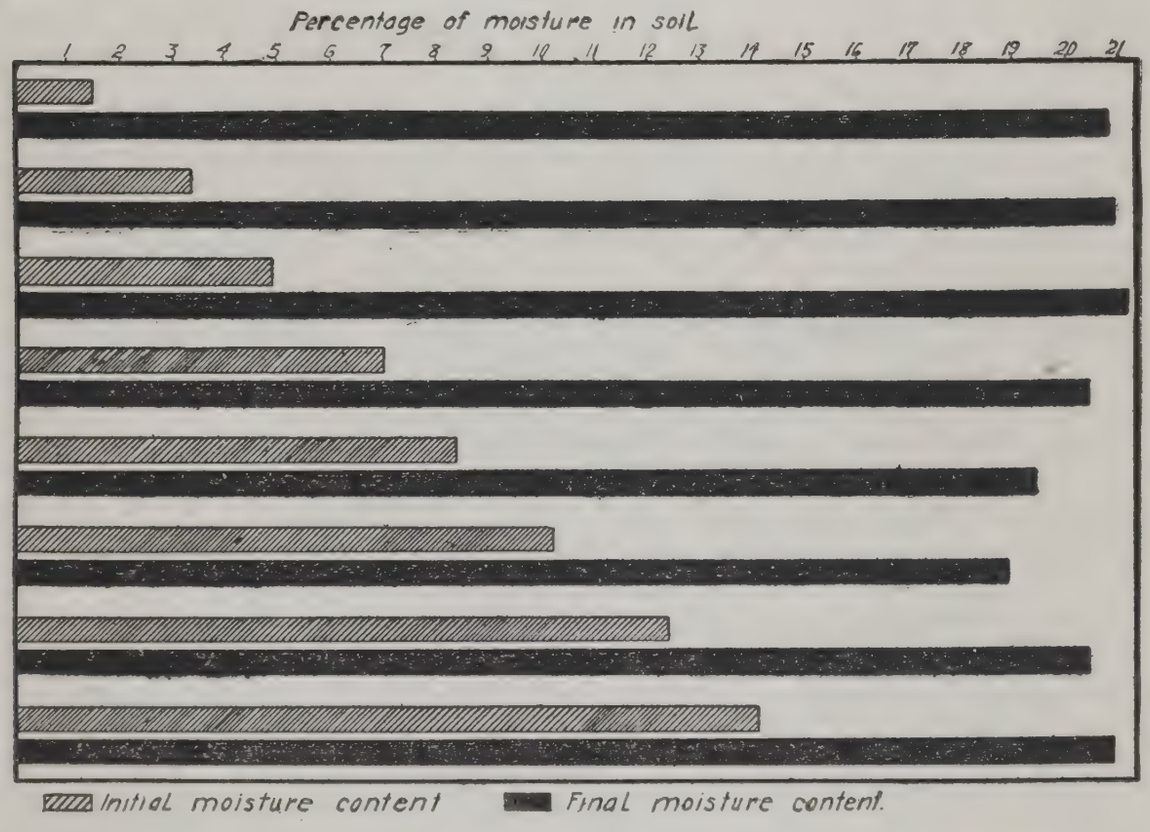
Percentage of moisture in soil
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Initial moisture content
Final moisture content

FIG. 20.—Diagram showing the effect of the initial percentage of water on the final moisture content of soils in contact with a wet loam having 30.45 per cent of water.

EFFECT OF VARIATION IN INITIAL PERCENTAGE IN SOURCE OF SUPPLY

Downward and upward movements as affected by varying initial percentages in the source of water supply were studied in this experiment. Here 12 glass cylinders 14 inches tall and 2 inches in diameter were filled with Greenville loam containing 2.12 per cent of water. Twelve similar cylinders were filled in duplicate with Greenville loam having 15.87, 18.48, 20.24, 24.55, 27.74, and 29.9 per cent of moisture, respectively.

In one set the moist soil was placed above and in the other set beneath the dry soil, in order to study the downward and upward movements. Good contact was secured between the dry and wet soil before the joints were sealed with paraffin. After six months (from Mar. 13 to Sept. 14, 1916) the tubes were taken down and the moisture determined in each 2-inch section. The rise and descent of the water in the dried

soil was observed through the glass and recorded for the first 46 days. These movements are shown in graphic form in figure 21. In

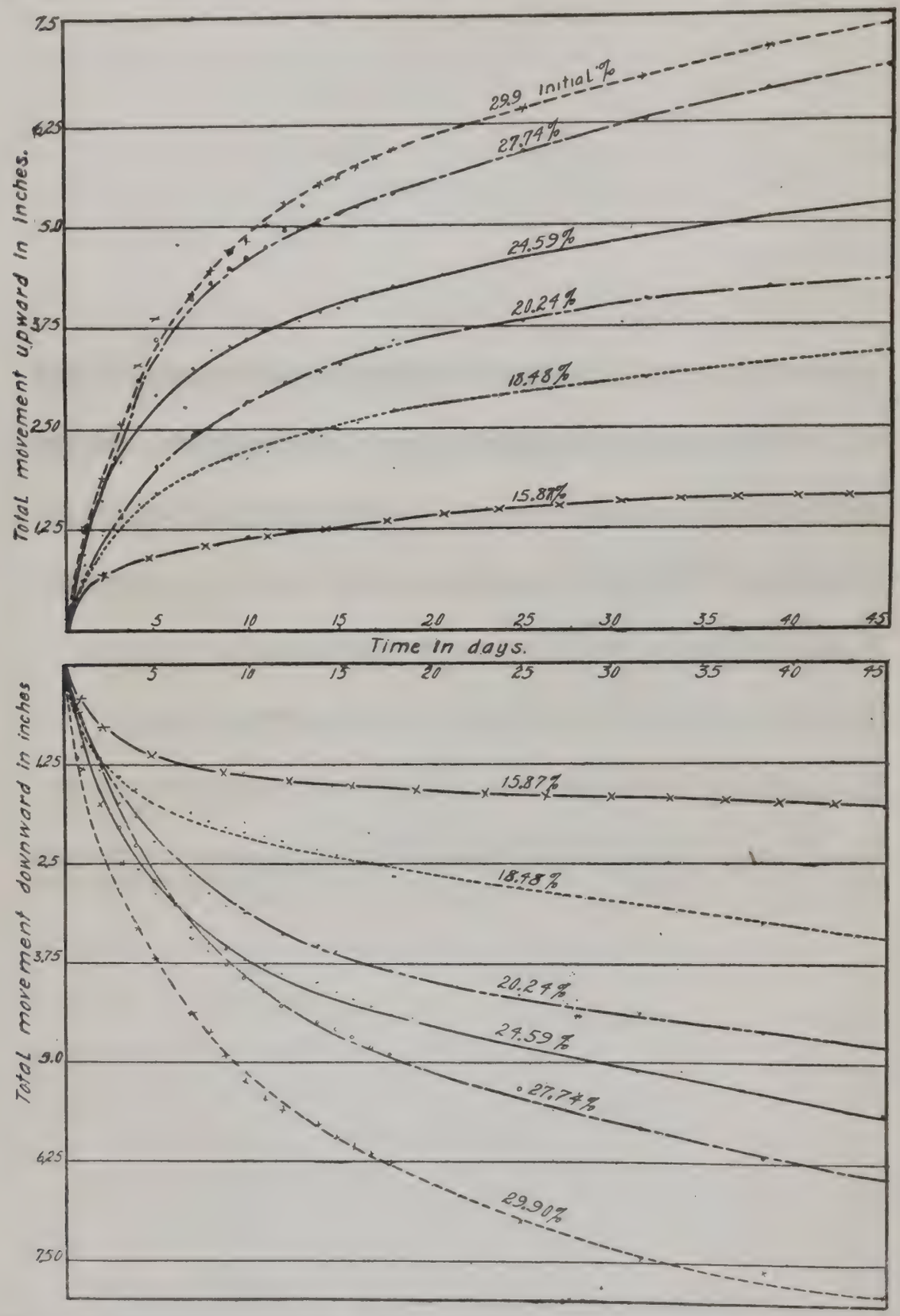

FIG. 21.—Diagram showing a comparison of the rate of capillary movement of moisture upward and downward through air-dry Greenville loam with a varying moisture content in the source of supply.

all cases the greatest rise and descent took place where the source of water was the soil with the greatest initial percentage of moisture. The

figure shows that as the initial percentage of water in the wet soil decreased, the length of time of the rapid moisture movement also decreased.

It was also found that the water moved downward into the soil faster than it moved upward and that an approach to an equilibrium is reached sooner by the downward movement. The moisture moved down farther than up during these 46 days. From this experiment it is seen that loam soil with as high as 18.5 per cent of moisture gives up water to air-dry soil at a very slow rate, especially after the first week. In all cases the rapid movement into the drier soil had practically ceased by the end of the first week.

EFFECT OF GRAVITY

With Varying Initial Percentages of Moisture in the Source of Supply

The data for the first part of this experiment on the effect of gravity on the movement of soil moisture were taken from the above experiment.

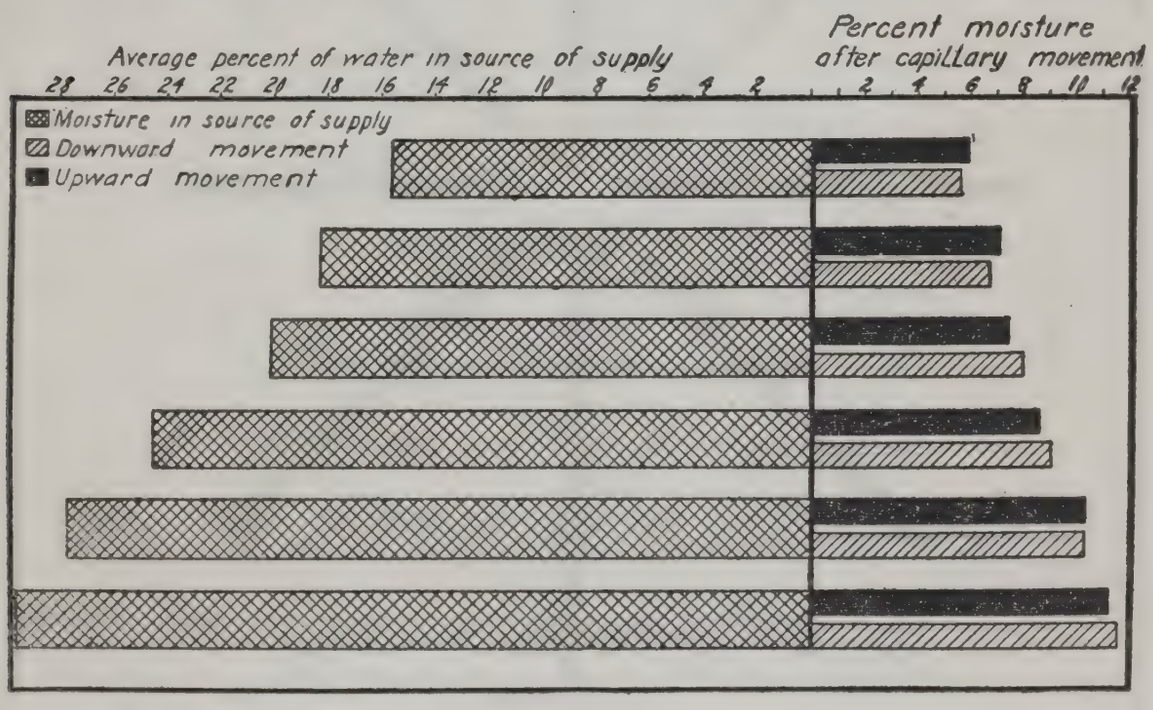
Average percent of water in source of supply
28 26 24 22 20 18 16 14 12 10 8 6 4 2
Percent moisture after capillary movement
2 4 6 8 10 12
Moisture in source of supply
Downward movement
Upward movement

FIG. 22.—Diagram showing the average final distribution of moisture which moved upward and downward by capillarity through Greenville loam, air-dried, with a varying moisture content in the source of supply.

Figure 22 shows how the average moisture content in each of the cylinders that originally had 2.12 per cent of moisture was affected by gravity where different quantities of water in the soil were used as sources of supply. That gravity plays relatively little part in the distribution of moisture in dry soils where the sources of water are moderately moist soils is the conclusion from this figure. There was slightly more moisture in the soil supplied by upward movement where the initial percentage of water in the soil supplying moisture was rather low, but the reverse was true elsewhere.

WITH A LARGE SOURCE OF MOISTURE SUPPLY

In the second experiment on the effect of gravity a tub similar to one described in a previous experiment was used. In this case the brass tubes were filled with Greenville loam having a moisture content of 5.54 per cent, while the tub contained Greenville loam with a moisture percentage of 30.25.

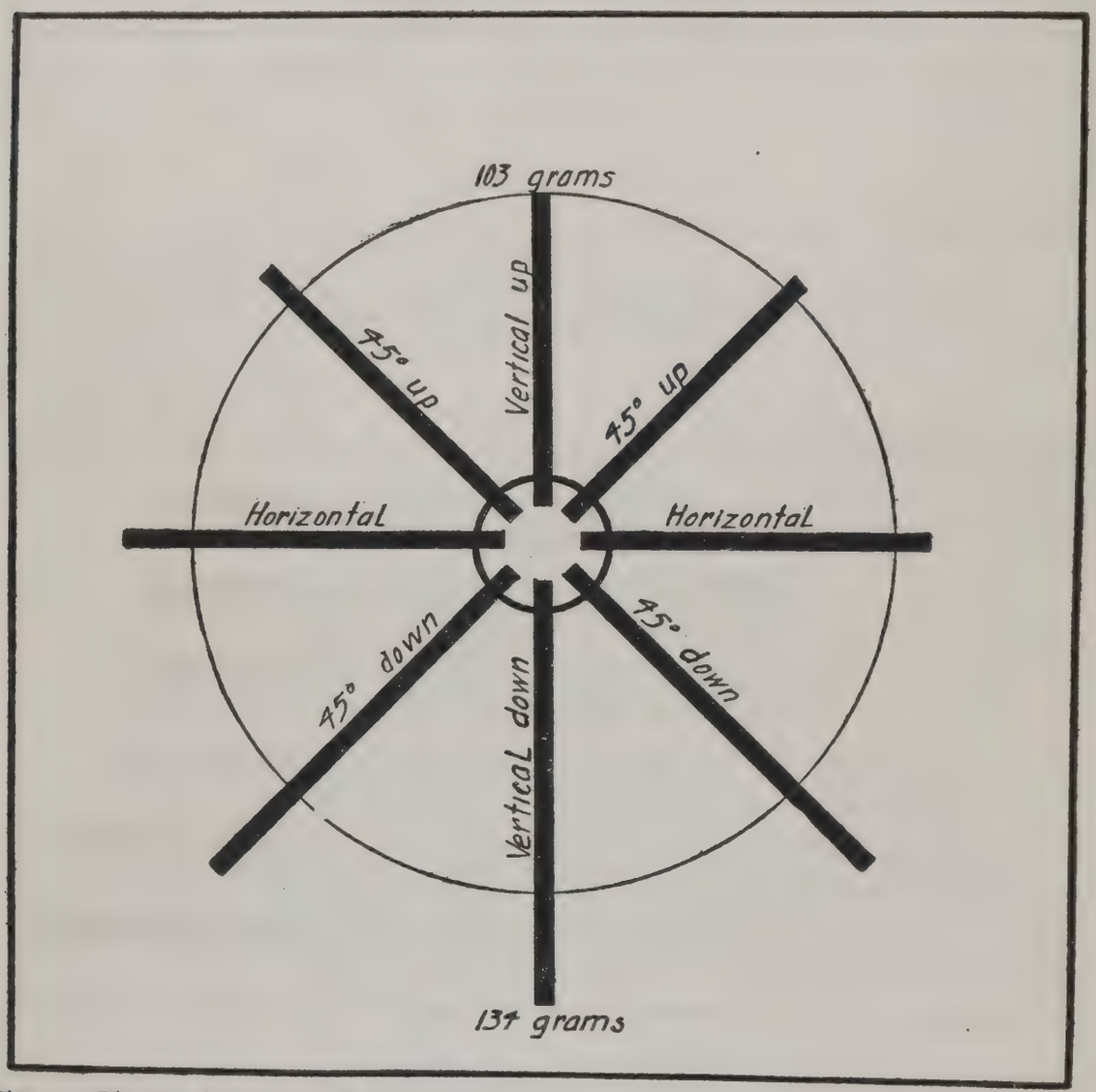

FIG. 23.—Diagram showing the effect of gravity on the quantity of water moved by capillarity through Greenville loam from similar soil containing 30.25 per cent of water as the source of supply.

The brass tubes were arranged in the form of a wheel, so that two were vertical, two horizontal, and four at angles of 45°. At the end of the experiment, which lasted from May 26 until September 13, 1916, the tubes, which had been weighed before being placed in contact with the moist soil, were taken down, reweighed, and the moisture content determined for each 2-inch section.

Figure 23 represents diagrammatically the position of the tubes and the moisture gained by each tube, the length of the line in the figure representing the moisture gained.

The greatest and least gains in moisture, as shown by the figure, took place where the movement was vertically down and up, respectively.

In the order of the quantity of water gained, the tubes were as follows: Vertically down, 45° down, horizontal, 45° up, and vertically up. In other words, gravity plays a very appreciable part in moisture movement where the source of supply is a fairly large mass of comparatively moist soil.

EFFECT OF SOIL TYPE

WHERE MOISTURE MOVED UPWARD FROM GREENVILLE LOAM INTO DIFFERENT SOIL TYPES

Greenville loam containing 28.36 per cent moisture was placed in bell jars 6 inches in diameter and 10 inches deep. These jars were sealed at the bottom. Through small openings in the top, glass tubes filled with air-dry clay, Greenville loam, and sand were inserted into the bell jars so the tubes were held vertically. The tops of the tubes and the junction with the bell jars were carefully sealed. From time to time during the experiment, which lasted from May 29 until October 18, 1916, the rise of the moisture in the tubes was recorded. At the end of the test the tubes were taken down and the moisture determined for each 3-inch section.

In figure 24 is shown the distribution of moisture by 3-inch sections in each of the three soil types. The figure shows a decrease in moisture, with an increase in distance from the point of contact with the moist soil. This decrease was rather gradual in the loam and sand, but was more abrupt in the clay.

Coarse sand, such as was here used, drew into itself a very low percentage of water, while clay took sufficient to increase its own moisture content to nearly that of the loam acting as the source of supply in 139 days. In the case of the loam, the moisture in the tube blended almost without a break into that of the source of supply.

The moisture moved farthest in the loam and least in the clay. This shows that clay offers considerable resistance to the movement of moisture, even when the source of water is a large mass of fairly moist loam.

WHERE MOISTURE MOVED HORIZONTALLY FROM GREENVILLE LOAM INTO DIFFERENT TYPES OF SOIL

In this case the Greenville loam, containing 30.45 per cent of water, to act as source of moisture, was placed in a tub similar to those described in previous experiments. Soils of the types shown in Table II, held in 24-inch brass tubes, were inserted horizontally into the tub, and the whole apparatus was well sealed.

The experiment was begun on May 24, and on September 11, 1916, the moisture determination for each 2-inch section was made.

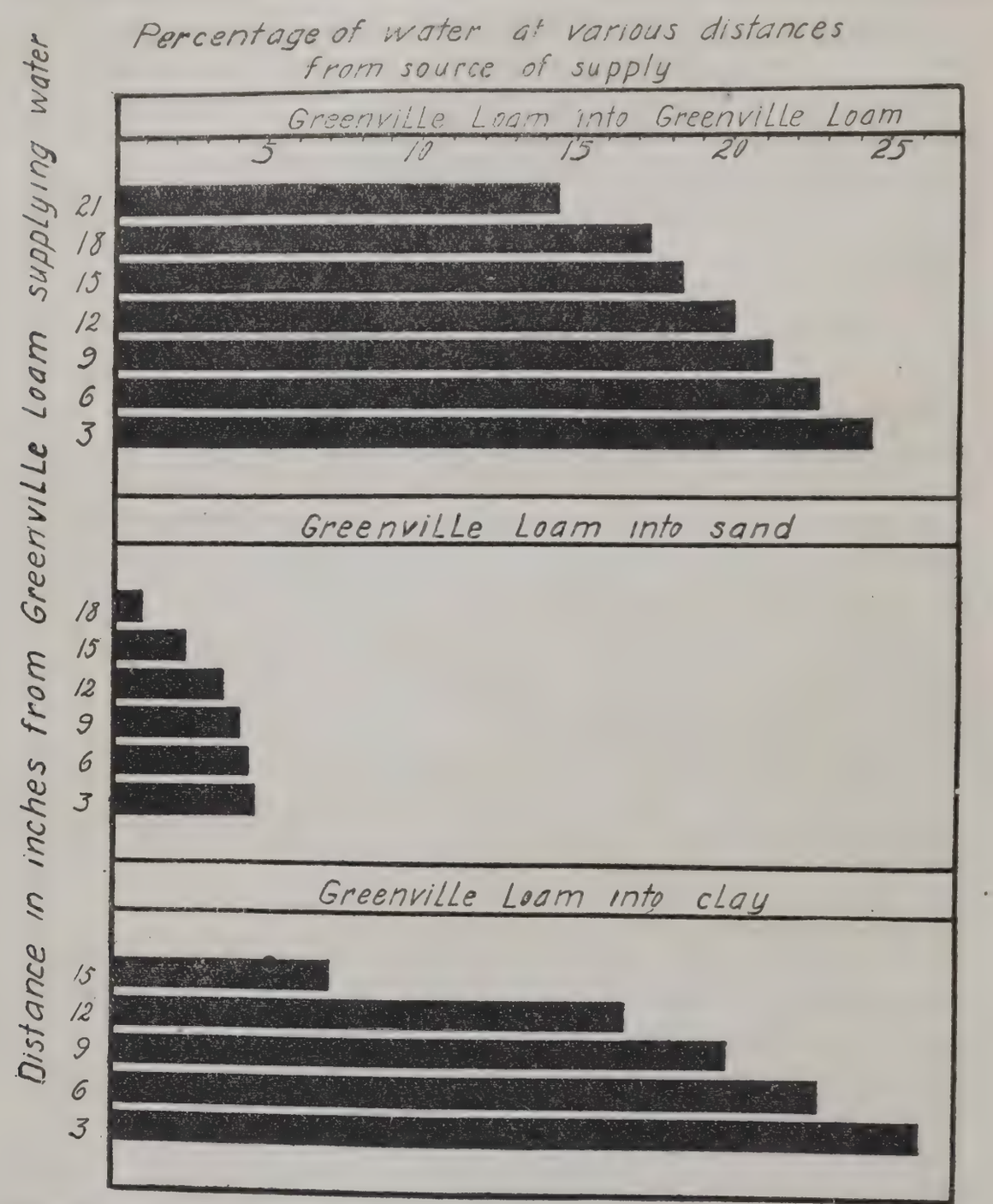

FIG. 24.—Diagram showing the effect of type of soil on the distribution of capillary moisture at different distances from the source of supply, after standing for 139 days. The source of supply was Greenville loam containing 28.36 per cent of moisture.

TABLE II.—*Air-dry soil types contained in the tubes used in tests of horizontal movement of moisture*

Tube No.	Type of soil.	Moisture.
		Per cent.
1	Clay	2. 17
2	Greenville loam	1. 88
3	Sand	. 20
4	Clay, 50 per cent; loam, 50 per cent	2. 19
5	Clay, 50 per cent; sand, 50 per cent	1. 20
6	Loam, 50 per cent; sand, 50 per cent	1. 03
7	Loam, ⅓; clay, ⅓; sand, ⅓	1. 64
8	Sand, 75 per cent; muck, 25 per cent	1. 58

Figure 25 gives the distribution, by 4-inch sections, in each of the tubes. Here, as in the previous experiment, it is shown that the moisture

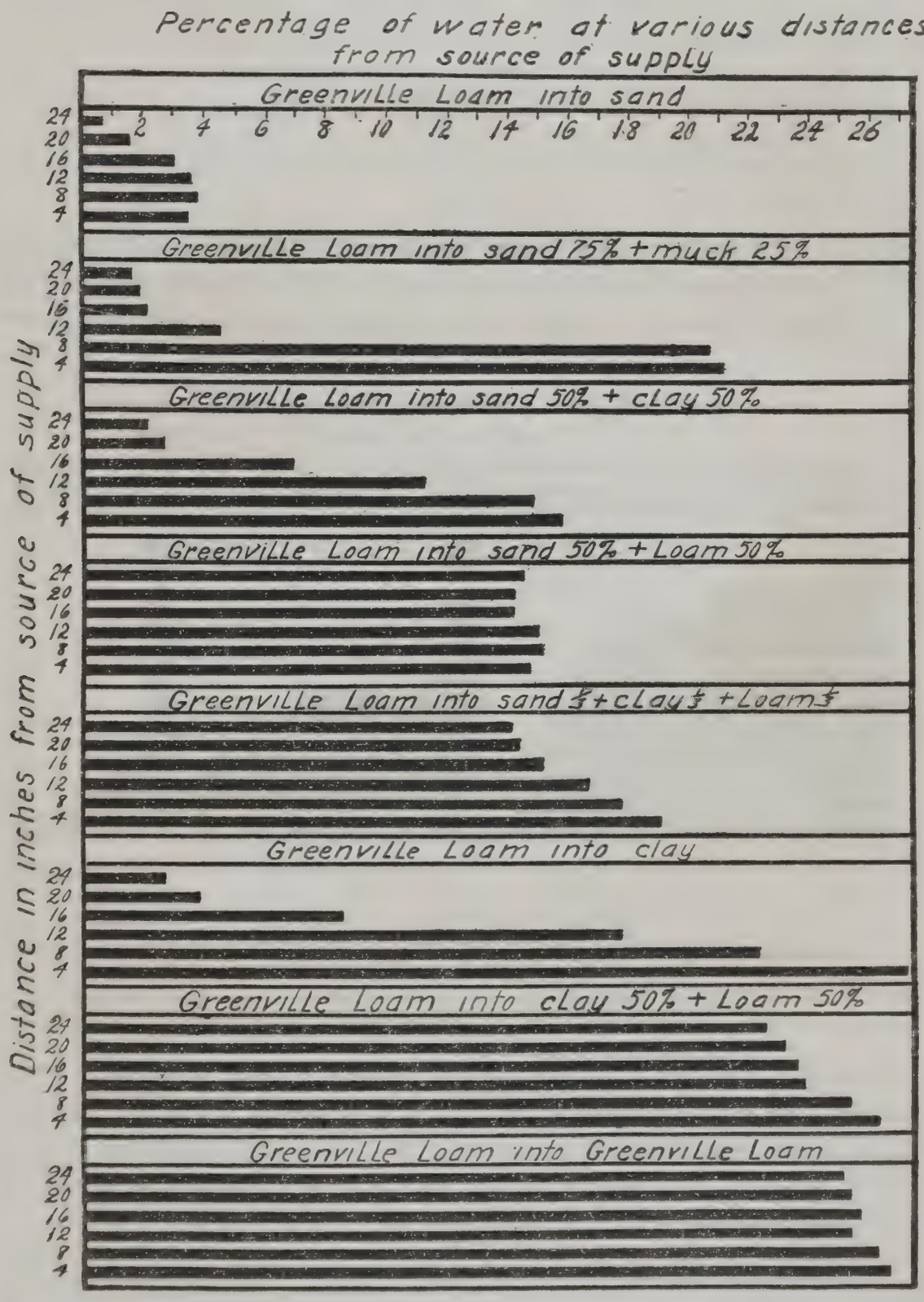

FIG. 25.—Diagram showing the effect of type of soil on the distribution of capillary moisture at different distances from the source of supply. The source of supply was Greenville loam containing 30.45 per cent of moisture.

tends to distribute itself with the greatest content nearest, and the least content farthest, from the source of supply.

This difference is not so great with the loam and the mixture of sand and loam, but it is very marked in the clay, the clay plus sand, and the

sand plus muck. Evidently where there is a large supply of moist soil, the moisture will tend to distribute itself uniformly throughout the soils to the full length of the tube. This tendency may be checked by an insufficient length of time, a weak attraction of the more remote sections for water, excessive frictional resistance such as is found in clay soils, or an exhaustion of the supply before the remote soil is reached.

Where Moisture Moved Upward from Different Soil Types to Greenville Loam

In this experiment studies were made of the ability of different soil types to supply moisture to Greenville loam. This was done by placing in bell jars, such as were used in a previous experiment, sand, clay, and Greenville loam having 7.77, 24.62, and 31.09 per cent of moisture,

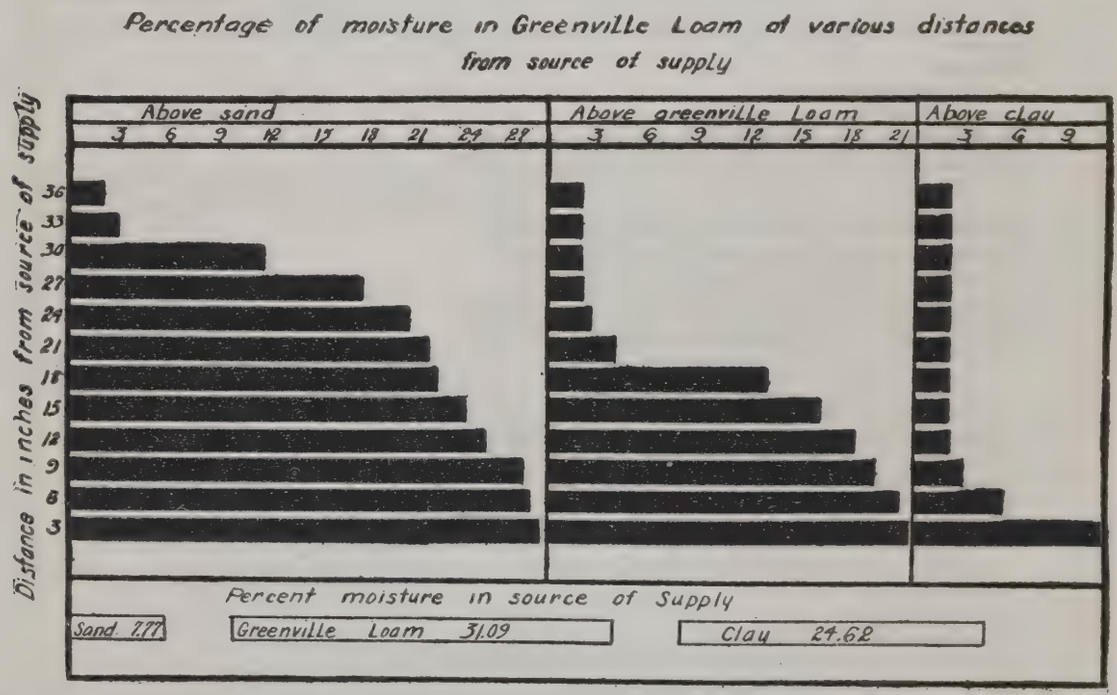
Percentage of moisture in Greenville Loam at various distances from source of supply
Above sand
Above greenville Loam
Above clay
Distance in inches from source of supply
Percent moisture in source of Supply
Sand 7.77
Greenville Loam 31.09
Clay 24.62

Fig. 26.—Diagram showing the distribution of moisture in air-dried Greenville loam in contact with sand having 7.77 per cent, Greenville loam having 31.09 per cent, and clay having 24.62 per cent of moisture.

respectively. Into these jars were then inserted the ¾-inch glass tubes filled with air-dry Greenville loam. A record was kept of the rates the moisture rose in each of the tubes. After the experiment had run 94 days, the tubes were removed and moisture determinations made for each 3-inch section of the tubes.

In figure 26 it is seen that here, as in the two previous experiments, the moisture content decreased with the distance from the source of water. Sand with only 7.77 per cent of moisture raised the moisture content of air-dry loam with which it was in contact to almost 30 per cent, and caused an appreciable increase in the moisture to a distance of over 30 inches. Clay containing 24.62 per cent of moisture, on the other hand, raised the moisture of the loam only slightly and to a distance of about 6 inches. When dry loam was left in contact with loam con-

taining 30 per cent of water, the former gained moisture for the first 21 inches only. The results indicate the value of fairly moist sandy strata as sources to supply moisture for heavier soils above, and the inadequacy of heavy soils below as moisture supplies.

Rate of Rise of Moisture

Figure 27 shows graphically the rate of rise of moisture obtained from the last two experiments on the effect of soil types. The most striking features of the curves are the extremely small rise of moisture from clay into loam and the exceedingly large and rapid rise from sand into loam. Other interesting points in the curves are (1) the small difference in the

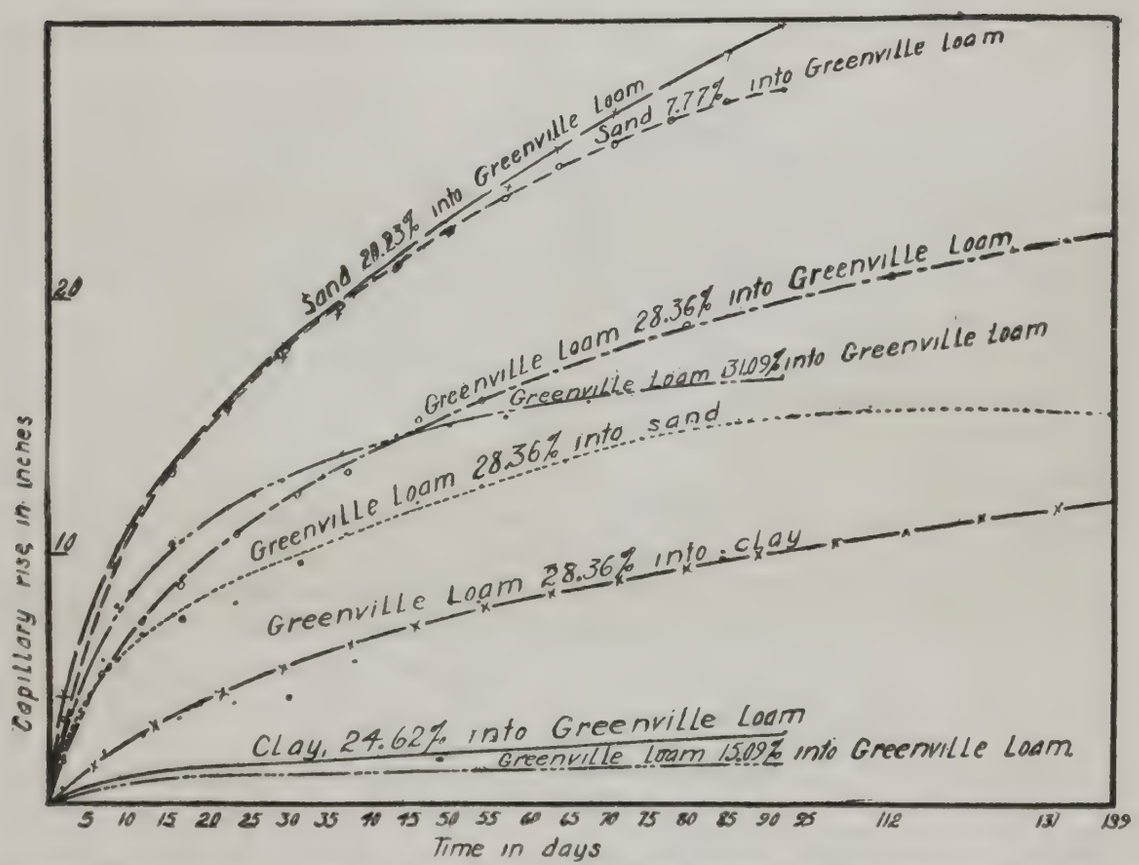
Sand 28.23% into Greenville Loam
Sand 7.77% into Greenville Loam
Greenville Loam 28.36% into Greenville Loam
Greenville Loam 13.09% into Greenville Loam
Greenville Loam 28.36% into sand
Greenville Loam 28.36% into clay
Clay, 24.62% into Greenville Loam
Greenville Loam 13.09% into Greenville Loam
Capillary rise in inches
20
10
5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 112 131 139
Time in days

Fig. 27.—Diagram showing the effect of type of air-dried soil on the rate of capillary movement from various soils used as a source of supply.

rapidity and the total rise from sands having high and low moisture contents into loam; (2) that this rise shows no sign of ceasing even after 94 days; (3) that movement from loam into loam, where the source of supply contains a large percentage of moisture, is quite rapid, but very slow where the source of moisture contains but 15 per cent of water; (4) that movement is at first quite rapid from loam into sand, but exceedingly slow after two weeks; (5) that movement from moist loam into clay is fairly slow, but continues for a considerable length of time.

These facts show the importance of having coarser subsoils rather than the reverse, because moisture moves slowly into them and rapidly up out of them into heavier soils above.

Effect of Layers of Different Soil Types

In the fifth experiment with soil types, bell jars filled with soil containing 14.7 per cent of moisture were used as sources of water supply for mixtures of soil types in glass tubes ¾ inch in diameter. The bell jars and glass tubes were arranged as in the previous experiments. In the first trial the soil in the tube consisted of a layer of sand followed by a mixture of sand and loam, then loam alone, and finally clay.

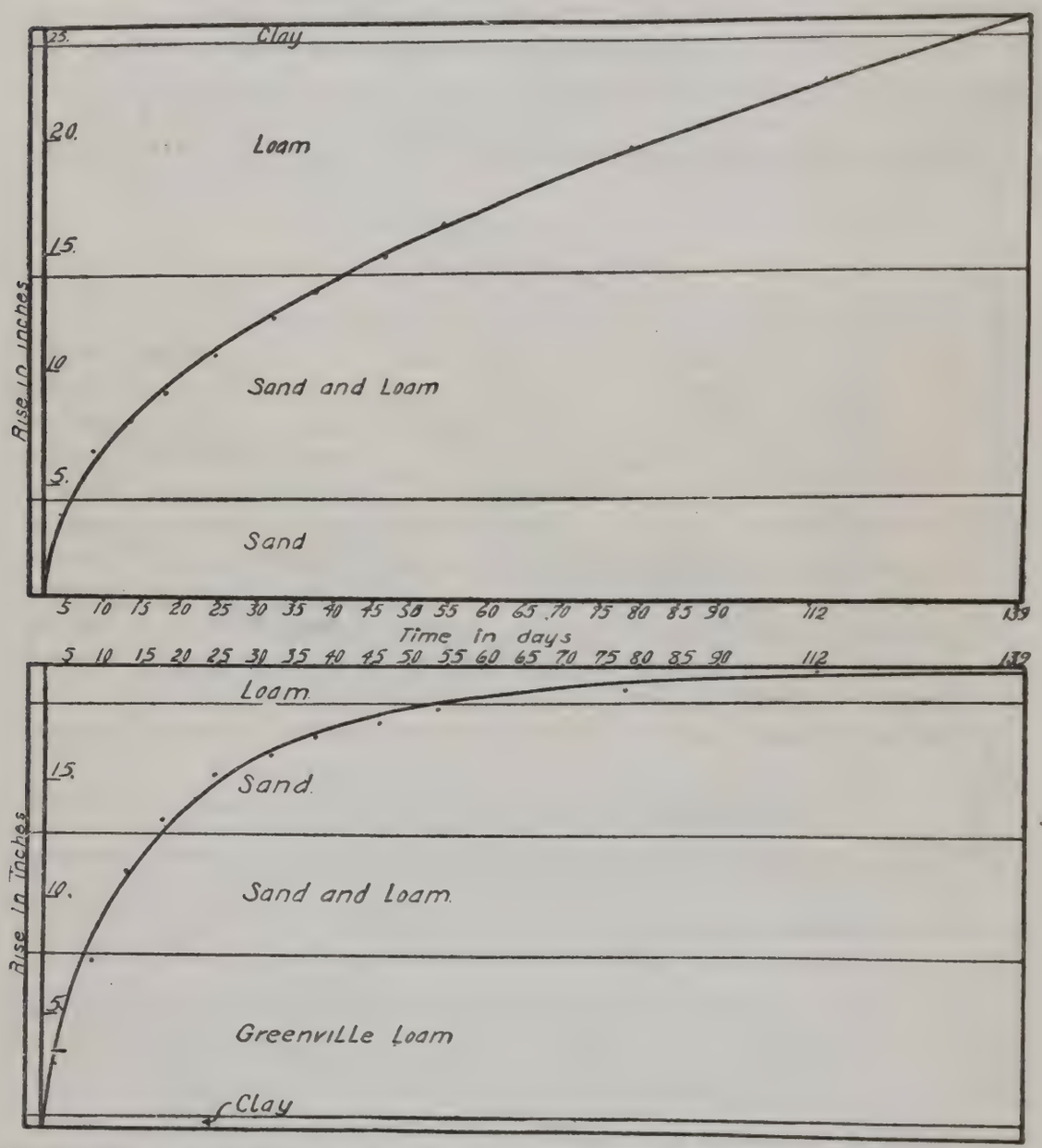

Fig. 28.—Diagram showing the rate of capillary movement through soil columns composed of layers of different types of soils.

In the second test the order of the soil types was reversed, the clay being nearest the source of supply. A record was kept of the rate of movement in each of these tubes, and the results are presented in figure 28.

With the soil increasing in fineness from the source of water, the curve shows a considerable and prolonged rise, while with the reverse order of fineness, the rise was very rapid for the first few weeks, but a decided

falling off occurred when the coarser layers were reached. In the latter soil type an equilibrium was approached fairly rapidly, while in the first there was still an appreciable movement after 139 days.

EFFECT OF SOURCE OF WATER SUPPLY

In Greenville Loam

In the discussion of figures 24, 25, and 26 it was pointed out that moisture tends to distribute itself with the greatest content nearest and the least content farthest from the soil acting as source of supply, no matter whether this soil be clay, loam, sand, or different soil types.

Figure 29, which represents the results of data taken from the experiment on the effect of initial percentage on the horizontal distribution

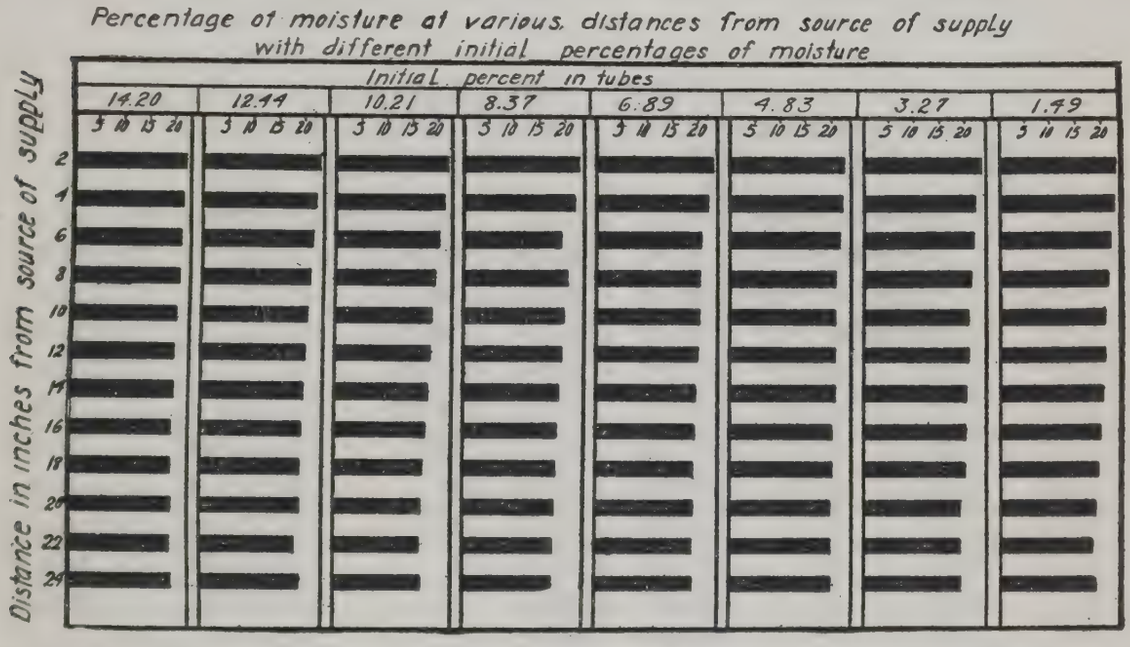

FIG. 29.—Diagram showing the horizontal distribution of capillary moisture at various distances from the source of supply in Greenville loam with different initial percentages of moisture. The source of supply in each case was Greenville loam with 30.45 per cent of moisture.

of moisture in soils in contact with a large amount of unsaturated Greenville loam, shows that no matter whether the movement takes place in soils of low or high initial moisture there is always more moisture near the source of supply than farther away. The figure shows that the difference between the nearest and the most remote sections is practically the same, irrespective of the original moisture content.

In Different Soil Types

These data were taken from the experiment on the effect of soil types where moisture moved horizontally from Greenville loam into different soil types.

Figure 30 shows the variation in the content of different soil types at different distances from the tub containing the moist Greenville loam. Here, again, are brought out the points illustrated in figures 24, 25, 26,

and 29. The figures, however, show even more clearly the great part played by soil types in determining the amount of moisture and the distance that it will travel from the source of supply in a relatively short time. For instance, very coarse and very fine soils (sand and clay) show the greatest variations, while in loam the difference is scarcely appreciable.

With the Action of Gravity

To show the effect of the distance from the source of water with gravity acting, figure 31 has been prepared from the data of the experiment represented in figure 23. It shows the distribution by 2-inch sections in the tubes which were in contact with moist Greenville loam in the tub. Here it is noticed that distance from the source of supply plays little or no part in the moisture content of the tubes that were vertically and 45°

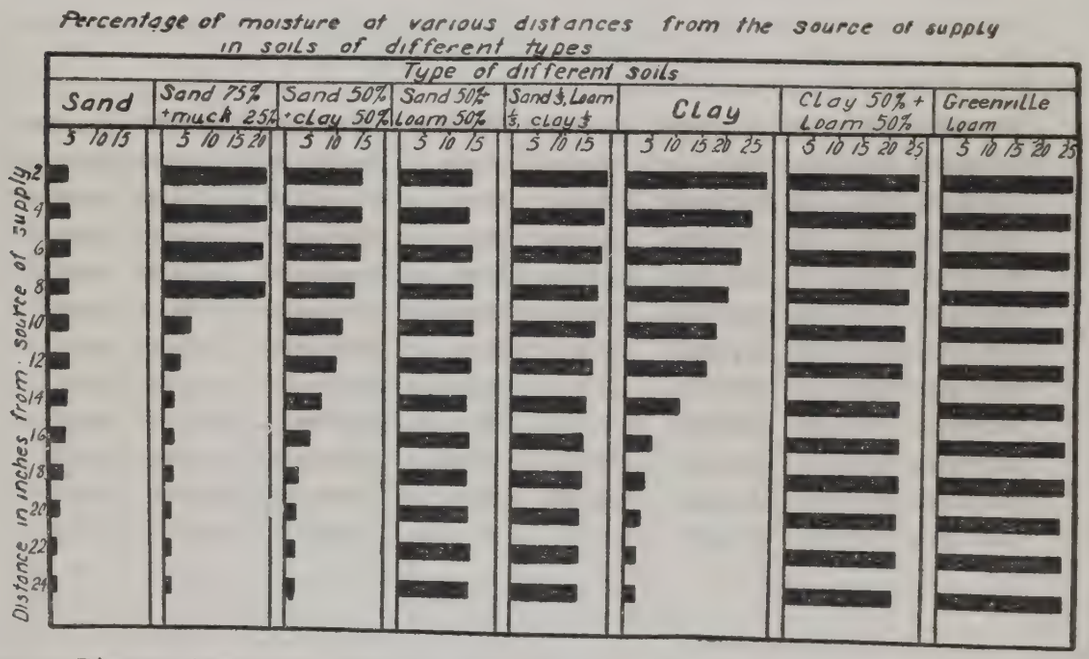

FIG. 30.—Diagram showing the horizontal distribution of capillary moisture at various distances from the source of supply in soils of different types. The source of supply in each case was Greenville loam having 30.45 per cent of moisture.

down. Where the movement was horizontal or up, however, the greatest moisture content was nearest the source of supply. The largest difference between the section nearest and that most remote from the wet soil was found in the column with the movement vertically up.

Figures 24, 25, 26, 29, 30, and 31 lend excellent support to each other in showing that, except where gravity acts, moisture will distribute itself with the largest amount nearest and the smallest quantity farthest from water held in moist soils, even after several months.

SUMMARY

(1) During recent years considerable difference of opinion has grown up regarding the importance of the capillary movements of soil moisture and also regarding the laws governing the final distribution of moisture in the soil.

(2) The present paper gives the results of soil-moisture experiments conducted in the laboratory and in the field under irrigation and dry-farming conditions. The experiments represent several thousand moisture determinations.

(3) The field studies include the effect of fallow, kind of crop, manure, irrigation water, surface mulches, cultural methods, and seasonal conditions on the movement and distribution of soil moisture.

(4) The laboratory studies include the effect of the initial percentage of moisture, gravity, soil type, source of supply, etc., on the movement and distribution of moisture in the soil.

(5) In field soils the moisture content of the fallow soils averaged greater than that of the cropped soils.

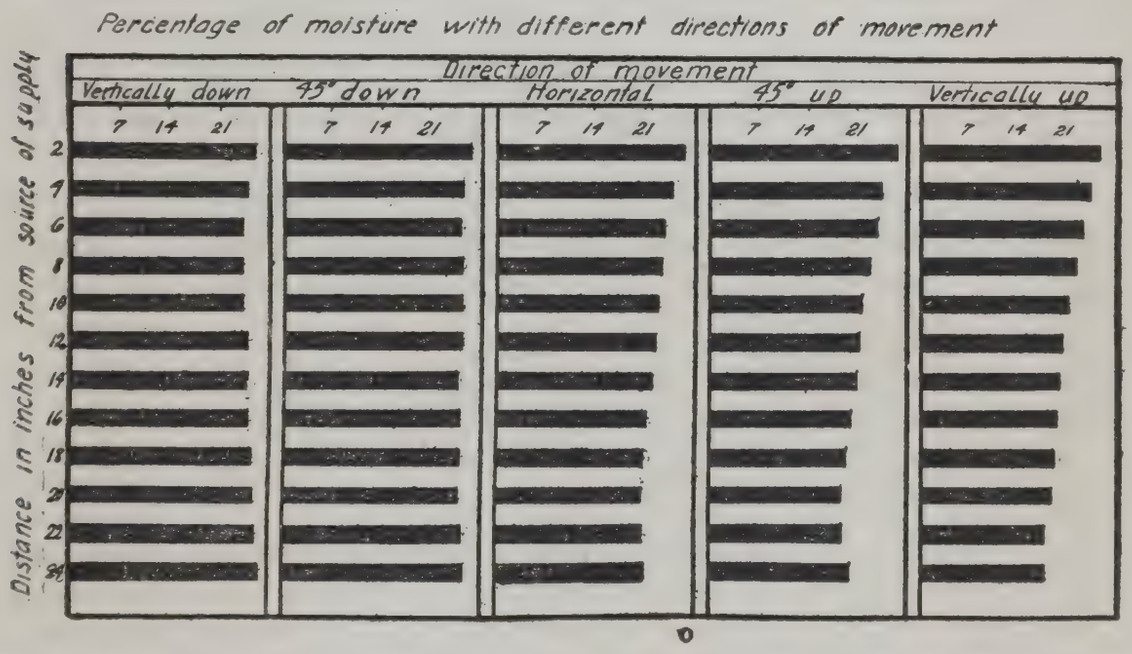

FIG. 31.—Diagram showing the distribution of capillary moisture at various distances from the source of supply as affected by gravity. The source of supply in each case was Greenville loam with 30.25 per cent of moisture.

(6) Unmanured irrigated land showed less difference in moisture between cropped and fallow than did the manured.

(7) Irrigation influenced the top feet of the cropped plots proportionately more than the fallow, but water did not appear to penetrate the fallow plots below 7 feet as readily as it did the cropped ones.

(8) Under dry-farming conditions the difference in moisture between cropped and fallow plots was not noticeable until after June 16. Cropped plots showed more fluctuation than fallow ones. Wheat, corn, potatoes, and peas drew most of their moisture from the first 4 feet in depth. The wheat land contained less moisture in the fall than the other cropped soils, with corn following.

(9) The increase in moisture due to applications of 5 to 7½ inches of irrigation water was felt to depths of 10 feet in 24 hours, although most of the increase was in the first 4 feet.

(10) The effect of mulches in preventing moisture loss under both irrigation and dry-farming was noticeable several feet below the surface of the ground, but the surface foot showed the greatest benefit from mulches. A straw mulch proved considerably better than a 2-inch soil mulch.

(11) Mulches on irrigated plots appear to influence the moisture content of the soil to greater depths than do those under dry-land conditions. A dry-farm plot kept free from weeds in 1916 but not mulched lost very little more water than one mulched 2 inches deep. A 6-inch cultivation on spring-plowed and a 2-inch cultivation on fall-plowed dry-farm land seemed to conserve the moisture best.

(12) Subsoiling 15 inches deep had little influence on the moisture; spring disking was rather a distinct benefit.

(13) That spring plowing under dry-farming conditions at Nephi conserves moisture better than fall plowing is indicated by an 8-year average. This difference in favor of spring plowing is shown more below the first foot than in the first foot, and more in the summer and fall than in the spring.

(14) A precipitation as small as 0.1 inch under dry-farming conditions could not be detected in moisture determinations soon after, but, when as much as 0.5 inch fell within a short time, an increase in moisture was noticed to a depth of 6 feet.

(15) When freely supplied with water, a soil with a high initial percentage of moisture will come to a moisture equilibrium sooner than a drier one, but if given time the drier soil will absorb a greater quantity through a long distance either upward or downward than will the wet one.

(16) The rate of moisture penetration in the first 10 days was nearly twice as great with initial percentages above 15 as with 5 or below, and nearly twice as rapid after a 15-inch irrigation as after a 5-inch one. Under the most favorable conditions 7 feet was influenced in 10 days.

(17) Moisture movement from soils of optimum moisture content into soils of differing initial percentages varied to an extent inversely as the initial content of the dry soil. At the end of six weeks, however, the amount of water actually in the soils still varied directly as the initial percentage.

(18) The higher the percentage of moisture in the soil supplying the water to a dry soil, the more rapidly and farther from the source of water did the moisture move.

(19) Even when the source of water was an unsaturated soil, greater and faster movement took place when the water was moving downward than upward. When the quantity of soil yielding the water was so small as to make the total moisture content of both moist and dry soils very low if equally distributed, the effect of gravity was not great.

(20) Moisture from a nearly saturated soil moved a greater distance into loam than into sand in 139 days and into sand farther than into clay. The clay, however, contained more moisture in the layer of soil

next the water supply than the others and sand contained by far the least.

(21) Sand, with 7.77 per cent of moisture, gave up its moisture to loam much more readily than did loam with 31.09 or clay with 24.62 per cent of moisture.

(22) The rate of rise of moisture from soils of varying fineness when used either as water sources or water absorbers varied inversely with the fineness. Water rose to a height of over 30 inches in a loam soil from a moist sand in 94 days, while from a moist clay it rose little more than 6 inches in this length of time. In all soils the most rapid rise of the water was during the period soon after being placed in contact with the water.

(23) Although the rise of the moisture was more rapid in the sand and loam than in the clay, the rise continued steady longer in the clay than in the others.

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A COLLETOTRICHUM LEAFSPOT OF TURNIPS

By B. B. HIGGINS,
Botanist, Georgia Agricultural Experiment Station

DESCRIPTION OF THE LEAFSPOT

During August, 1914, young turnip plants (*Brassica rapa*) with leaves badly affected by a leafspot disease were brought to this Station from near Macon, Ga. The grower stated that during two previous seasons the disease had been very destructive to young turnips, but observations on specimens sent from this field indicate that the greater part of damage was probably due to a bacterial softrot of the roots. Since that time the diseased plants have been collected locally several times. The disease rarely killed the plants or proved very serious, other than in disfiguring and occasionally killing the tops.

The spots are small (¼ inch or less in diameter), circular in outline, and of a pale-gray or straw color. Usually no sign of a parasite can be seen with the unaided eye or even with a good hand lens; but, if the spot has developed under very moist conditions, both surfaces are covered with a salmon-pink layer of spores, a condition which is evident to the unaided eye. Under the microscope this layer is found to be composed of small, rod-shaped, 1-celled spores which singly appear colorless. They are borne on short sporophores which arise in small clusters from a delicate stroma in the surface of the leaf. Intermixed with these sporophores are prominent, long, black setæ, indicating at once the affinity of the fungus to the genus Colletotrichum.

Cultures of the fungus were readily obtained by sowing the spores in an agar plate. The mycelial growth was rather inconspicuous on all media, much more so than that from a culture of *Glomerella cingulata* from a decaying pear. Green bean pods, steamed in an autoclave and inoculated with the fungus from turnips, were covered in a few days with a thick layer of salmon-colored spores. On corn-meal agar [1] the acervuli, instead of being scattered evenly over the surface as on bean pods, were grouped in clusters. In old cultures on various media black structures having the appearance of perithecia were produced in abundance; but, when examined under the microscope, these were found to be only dense clusters of setæ. No perithecia were ever found either in cultures or on the infected leaves.

[1] SHEAR C. L., and WOOD, Anna K. STUDIES OF FUNGUS PARASITES BELONGING TO THE GENUS GLOMERELLA. U. S. Dept. Agr. Bur. Plant Indus. Bul. 252, p. 15. 1913.

INOCULATION EXPERIMENTS

Seedlings of the Purple Top variety of turnips, which had been developed in pots in the greenhouse, were sprayed with a suspension of the fungus spores in water. For this purpose a bean-pod culture, covered with the pink spore mass, was shaken in sterilized water. The suspension was then poured into a sterile atomizer used for spraying. At the same time similar seedlings were sprayed with sterile water, and both lots were covered with bell jars during the first four days. On the fourth day dark water-soaked spots began to appear on the plants sprayed with the spore suspension. The spots soon became very numerous and faded to the light-straw color characteristic of naturally infected spots. The control plants, sprayed with sterile water, remained free from the disease.

On March 15 several plants of mixed varieties from seed sown in the field the previous autumn were transferred to pots and carried into the greenhouse. After the plants had recovered from the transplanting and had begun to grow, they were inoculated as described above. Abundant infection was obtained on all varieties, indicating that probably no varieties of turnips are immune. Not only the leaves but also the stems and seed pods showed infection. Some of the very young seed stalks were killed, the whole outer surface being covered with anastomosed spots.

Inoculations were also made in a similar manner on radish (*Raphanus sativus*), cabbage (*Brassica oleracea capitata*), collard (*Brassica oleracea viridis*), and lettuce (*Lactuca sativa*). The inoculations on radish plants gave abundant infection. The radish seemed to be fully as susceptible as the turnip. On cabbage a few spots developed, but not nearly so abundantly as on turnip and on radish. Collards seemed to be slightly more susceptible than cabbage, but no naturally infected plants of either have ever been found in the field. The lettuce plants showed no sign of infection, though inoculated on various occasions.

A few cross-inoculations have been made in studying the relation of this fungus to other allied forms. Several turnip plants in each of five pots were inoculated as follows: No. 1 with the Colletotrichum from turnip, No. 2 with conidia of *Glomerella cingulata* from pear, and No. 3 with conidia of *Glomerella gossypii* from cotton bolls. The two others were not inoculated, but were given otherwise similar treatment to serve as control plants. On the fifth day spots began to appear on the plants of pot 1 sprayed with the Colletotrichum from turnip, and after a few days infection became so abundant that all the leaves were killed on these plants. No spots ever occurred either on the control plants or on the plants of pots 2 and 3.

At the same time three sound bean pods were sprayed with a water suspension of conidia of the Colletotrichum from turnip, five others were likewise sprayed, after being pricked or scratched with a sterile needle, and similar numbers to serve as controls were sprayed with sterile

water. All were inclosed in flasks for four days. No infections occurred, the wounds on both inoculated and uninoculated pods healing normally.

Six sound, firm apples were washed with a 1-to-500 solution of mercuric chlorid, rinsed in sterile water, and placed three in each of two sterile culture dishes. Three were punctured with a sterile scalpel and inoculated with conidia and mycelium from a culture of the turnip fungus; and the three others were punctured in a similar manner and inoculated with conidia and mycelium from a culture of *Glomerella cingulata* from pear. All were left at room temperature in the laboratory. After a month one of those inoculated with *G. cingulata* was almost entirely decayed, and each of the others so inoculated showed spots an inch or more in diameter, while those inoculated with the species of Colletotrichum from turnip showed only slight decay immediately within the wound. Later, as the fruits began to ripen, the decay spread until the whole of each was involved.

SEED INFECTION

As previously mentioned, inoculations showed that the seed pods were readily and abundantly infected. In view of the fact that it has been shown that under similar conditions the mycelium of some other species of this genus, notably *Glomerella* (*Colletotrichum*) *lindemuthianum* Shear and *G.* (*Colletotrichum*) *gossypii* Edgerton, enters the seed and remains dormant there during dormancy of the seed, this observation was of special interest; and experiments were planned to determine whether this was true for the turnip fungus.

During the spring of 1915 several old turnip plants in the field were transferred to pots and brought into the greenhouse to produce seed. When seed pods of various ages, from flowers to almost mature pods, had formed on a stalk the whole seed stalk was sprayed with a suspension of spores in water and then covered for a few days with a glass cylinder. Within a short time practically every pod on the inoculated plants showed one or more spots, and on many the entire surface was diseased. When the seed had ripened, the stalks were cut and hung in the storeroom until the experiment could be completed.

At various times during the following fall and winter seed were carefully shelled out, counted, and planted in pots in the greenhouse. Many seed from badly infested pods were plainly shrunken and dead. Less than half germinated. In one lot of 500 seed planted only 14 germinated. In all more than 2,000 seed were planted; but in no case could any diseased spots be found on the cotyledons or hypocotyl of the seedlings and none developed on the leaves.

Some of the diseased seed pods were also killed, embedded in paraffin, cut, and stained with various stains; but no trace of mycelium was ever found in living seed. It seems that, when the fungus enters a seed, the young embryo is killed at once, and the fungus probably dries up and

dies along with the seed. This is indicated by the macroscopical and histological appearance of the seed, and also by the results of the germination tests, in so far as the negative results can be held to justify a conclusion. It might readily be expected to happen in seed so small as those of the turnip.

IDENTITY OF THE FUNGUS

The form genera Colletotrichum and Gloesporium, comprising the group to which this organism belongs, are very difficult to separate into species because of the fact that many species are morphologically very variable and are rather general parasites—that is, a single species may infect and produce some form of disease in a great variety of host plants, as shown by the work of Shear and Wood [1] and others. Therefore one is necessarily more or less uncertain as to just how much reliance should be placed on morphological structures or on inoculation tests in determining the limits of species.

The results of cross-inoculations indicate that the turnip fungus is probably not identical with either *Glomerella lindemuthianum*, *G. gossypii*, or *G. cingulata*. The last-named species, however, according to the views of Shear and Wood,[1] contains several forms which are more or less distinct both morphologically and phisiologically. Therefore, if this view is accepted, it is impossible to determine the limits of this species in the absence of the ascigerous stage.

Two related forms, *Gloeosporium concentricum* (Grev.) Berk. and Br.[2] and *Colletotrichum brassicae* Schulz and Sacc.,[3] have been described on species of Brassica. Unfortunately specimens of neither of these could be obtained for comparison; but specimens of the turnip fungus were sent to Dr. C. L. Shear, of the Bureau of Plant Industry, who compared it with *G. concentricum*, which, he says, is entirely distinct. He expressed the opinion, however, that the turnip fungus might be identical with *C. brassicae*, specimens of which were not available to him. This species was described as occurring on decaying stems of *Brassica oleracea* and *B. caulocarpa;* but the characterization was very brief and, in view of the recent work in this group, is of little value in determining relationships.

The fungus and the disease produced on turnip leaves is characterized as follows: Spots small, circular, or nearly so, 2 to 5 mm. in diameter, sometimes anastomosing and forming larger spots of irregular shape, pale grayish or straw colored; acervuli small, scattered over both lower and upper surface of spot; stromata subepidermal, delicate; conidiophore short, tapering abruptly to a slender sterigmata to which the spore is attached; conidia cylindrical, 13.5 to 19.5 by 4 to 5.5 μ, hyalin, 1-celled; setæ dark brown to black, slender, 20 to 42 by 3 to 5 μ, 1- to 3-septate.

[1] SHEAR, C. L., and WOOD, Anna K. Op. cit.

[2] GREVILLE, R. K. SCOTTISH CRYPTOGAMIC FLORA. v. 1, pl. 27 (col.). Edinburgh, 1823.

[3] SCHULZER VON MÜGGENBURG, Stephan, and SACCARDO, P. A. MICROMYCETES SCLAVONICI NOVI. *In* Rev. Mycol., ann. 6, no. 22, p. 79. 1884.

On the stems the spots are more elongated parallel with the long axis of the stem.

The fungus seems to differ morphologically from *Colletotrichum brassicae* Schulz. and Sacc., especially as to shape and size of spores (Pl. 13, *A*; 14). (The spores of *C. brassicae* are described as fusoid, slightly curved, and 19 to 24 μ in length.) But it seems best to refer it tentatively to this species until a careful comparison of the two forms can be made.[1]

SUMMARY

An apparently new leafspot of turnips has been found in various localities of Georgia.

The disease also attacks the stems and seed pods, but experiments indicate that the fungus is not carried over in the living seed.

The fungus causing the disease is tentatively referred to *Colletotrichum brassicae* Schulz. and Sacc.

The spots are much smaller than the similarly shaped spots produced by *Cylindrosporium brassicae* Fautr. and Roum., which has been very abundant in this region during the past two years (Pl. 13, *B*). Both organisms are frequently found on the same plant.

[1] Specimens of this fungus were submitted to Dr. P. A. Saccardo, who finds that the fungus is not identical with *Colletotrichum brassicae*. He considers it a new species, to which he gives, in a note received after this article had been forwarded for publication, the following name and diagnosis:

Colletotrichum Higginscanum, species novæ. Maculis amphigenis, crebris, subrotundis, 2–4 mm. diam. pallide alutaceis, marginulo elevato, angusto virescenti-cinctis; acervulis punctiformibus, aegre visibilibus; setulis parcis filiformibus, fuligineis, sursum pallidioribus, 1–2-septatis 45–70=3–6, rectusculis; conidiis terete-fusoideis, 15–17=3–33, utrique obtusatis, pluriguttulatis, rectis, hyalinis; conidiophoris paliformibus, parce septatis, 16–19=6, subhyalinis.

Hab. in foliis adhec vivis *Brassicae Rapae*, Georgia, Am. bor. A *Coll. Brassicae* recedit, maculis, situ, conidiis non curvis, etc.

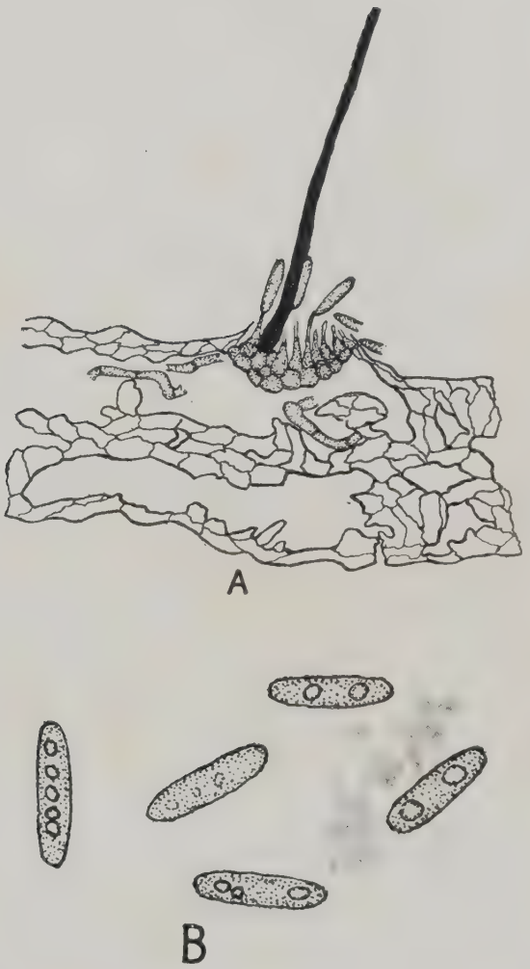
PLATE 13

A.—Leaves of a turnip nine days after inoculation with conidia of *Colletotrichum brassicae*. Slightly reduced.

B.—A turnip leaf showing spots produced by *Cylindrosporium brassicae*. Slightly reduced.

A

B



A

B

PLATE 14

Colletotrichum brassicae from turnip:

A.—Section through an acervulus on a turnip leaf. × 364.
B.—Conidia from a turnip leaf. × 728.

BLACK ROOTROT OF THE APPLE[1]

By F. D. FROMME, *Plant Pathologist*, and H. E. THOMAS,[2] *formerly Assistant Plant Pathologist, Virginia Agricultural Experiment Station*

INTRODUCTION

An unusually destructive rootrot of the apple (*Malus sylvestris*) is prevalent in the chief orchard sections of Virginia. The disease has been known to the growers for a number of years, but it is only quite recently that considerable interest has been manifested in it and a technical study undertaken at the Virginia Experiment Station.

The first published record of the disease, by Reed and Crabill (10) in 1913, contains a brief mention of a rootrot, with the suggestion that the cause may be one or more mushrooms. Subsequent preliminary notes by the same authors (11) and by Crabill (1) have outlined the general symptoms and indicated the importance of the problem. Fulton and Cromwell (5), in an abstract, briefly described a "black rootrot" of apple found in Pennsylvania and North Carolina which appears very similar to and is probably identical with the disease under discussion. In a preliminary note the writers (3, 4) have stated that the rootrot of apple in Virginia is probably due to one or more species of Xylaria and have designated it "Xylaria rootrot." As a descriptive common name "black rootrot" is preferable and will be used in the belief that the assumed identity of the Virginia and North Carolina rootrot diseases will be confirmed.

The disease is most prevalent in the middle and north "Valley," "Piedmont," and "Appalachian" sections of Virginia, and is probably present to some extent throughout the State. Our information is based on conditions as found in Alleghany, Rockbridge, Albemarle, Nelson, Augusta, Rockingham, Botetourt, Montgomery, and Frederick Counties. Losses of trees ranging between 5 and 25 per cent of the entire orchard have been observed. These losses, together with the high death rate of replants, which will invariably exceed that of the original trees in a stated period of years, make the disease a most formidable one. Financial losses from rootrot are, of course, very considerable.

SYMPTOMS OF ROOTROT

Many of the superficial symptoms of the disease may equally well characterize injuries due to other agencies such as winter injury, malnutrition, attacks of mice or rabbits, tree borers, woolly aphis, crown-gall, and collar-blight; but the combination of all symptoms, particu-

[1] Paper No. 47 from the Laboratories of Plant Pathology and Bacteriology, Virginia Agricultural Experiment Station.

[2] Now Assistant Plant Pathologist, Porto Rico Agricultural Experiment Station.

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larly those of the root system, affords a reliable basis for diagnosis. The first indications of an attack of rootrot are seen in the foliage. The leaves are paler in color than the normal green and have a yellow cast, an appearance of unthriftiness, and are smaller than normal. The thinness of the foliage later attracts attention (Pl. 15, *A*, *B*). This appearance is produced by a failure of many of the lateral buds to develop and by a check in length of the terminal growths. In later stages one or more of the main branches may die, while others may appear normal, but more commonly the general death of the tree results.

Trees of bearing age in late stages of rootrot have a tendency to heavy bearing, the fruit being small and poor in quality. One of the most reliable signs is an inclination of the trunk, the lean being directed away from the most seriously affected roots. Affected trees appear to die rather suddenly, but in most cases symptoms of rootrot have been present for a year or more; trees are rarely, if ever, killed within a single season from the time of infection. This is shown by a marked check in the terminal growth of branches which usually extends back over a period of two or more years and indicates the cumulative effect of a comparatively slow-acting parasite. Measurements of the length of terminal growths of two contiguous 6-year-old York Imperial apple trees, one healthy and the other affected with rootrot, gave the averages shown in Table I. The affected tree shows a marked check in growth beginning in 1915. Plate 15, *E*, shows representative terminal growths of these trees; the check in growth, the suppression of lateral buds, and the decrease in number and size of the leaves are apparent.

TABLE I.—*Average terminal growth of healthy and of diseased York Imperial apple trees*

Year.	Healthy tree.	Rootrot tree.
	Inches.	*Inches.*
1913	11. 25	13. 00
1914	5. 25	7. 83
1915	8. 90	. 75
1916	10. 00	1. 16

Death from rootrot may result at any stage in seasonal development, but the majority of trees probably succumb during the fall or winter. When death takes place during the growing season, the leaves brown and shrivel and hang on for sometime. Trees of any age may be subject to attack. The greater percentage dies between the ages of 12 and 20 years; a few may die as early as five years or younger. Trees on newly cleared land from which the stumps of forest trees have been removed shortly before planting usually die more rapidly and in greater numbers than those planted on cultivated land. A high percentage of the replants set where trees affected by rootrot have been removed die from the same disease (Pl. 17, *B*). Replant death commonly begins at three years of

age, and the percentage of death at seven years may equal or exceed that of the original trees at 15 years. All varieties of the apple probably suffer equally from the disease. We have found it equally prevalent on York Imperial, Winesap, Ben Davis, Black Twig, Grimes Golden, Albemarle Pippin (Yellow Newtown), and other varieties under equal conditions of exposure.

The appearance of roots of affected trees is quite characteristic. Young trees in advanced stages of infection may readily be uprooted by hand. In uprooting, the larger roots break off near the trunk, and often only a few small superficial roots support the tree. The bark, when not too far disintegrated, is covered with a thin black encrustation which is easily peeled off. The wood is brown and is marked with dark-brown zonations. On recently killed roots the wood is firm, and the zonations may penetrate it to some depth. The margin between sound and diseased bark and wood is sharply marked by a change in color, and thin brown strands may extend into the sound tissue for some distance. Sunken, discolored areas are usually found on the surface of the sound root beyond the main lesion (Pl. 17, *C*). They have the appearance of surface infections and may be superficial, or may penetrate to some depth. Usually but little evident mycelium is present on the surface of roots or within them. In advanced stages of decay roots are punky and brittle and vary in appearance; various fungi may be present and acting on them. Rhizomorphoid strands have been found associated with this rootrot in a few cases only, and then on roots in advanced stages of decay. The crown of the tree almost invariably shows the discoloration of the wood and bark found on the roots. The discoloration may extend up the trunk a foot or more above the surface of the ground and is often restricted to one side. Trees showing recognizable foliar symptoms of the disease are found to have the greater part of their root system affected. The initial infection of the root system may take place at any point, and the infection apparently progresses with equal rapidity toward and away from the crown. Infection may be communicated laterally to healthy roots in contact with diseased roots through uninjured rootlets or through wounds in large roots. Infected roots die back to the crown establishing the infection there, and the sound roots become infected subsequently through their attachment with the crown. Death of the tree probably results within a comparatively short time after the infection becomes established in the crown. Figure 1 shows the condition of the root system of a tree which showed pronounced rootrot symptoms.

FUNGI ASSOCIATED WITH ROOTROT

The absence of fruiting stages of fungi on affected roots has been noteworthy. The early removal of diseased trees as practiced in most orchards partly explains this. Perithecial stromata of *Xylaria polymorpha* (Pers.) Grev. have been found on the roots of several affected apple trees in two orchards at Barber (Pl. 15, *C*; 17, *D*), and numerous

stromata of *X. hypoxylon* (L.) Grev. appeared at the base of a dead apple tree at Blacksburg (Pl. 17, *A*). These had produced but few spores at the time of collection (January), but sporulated abundantly after being placed in moist chamber for a month (Pl. 17, *F*). Carpophores of *Clitocybe monadelpha* (Morgan) Sacc. were found at the base of several trees in one orchard at Middletown, but the relation of this fungus to the rootrot problem has not been determined. Affected roots brought to the laboratory and placed in moist chamber have developed conidial stromata of *X. hypoxylon* in a few cases (Pl. 15, *D*).

Isolation studies from roots in various stages of attack have been carried on during the past two growing seasons (1915 and 1916) in continuation of previous studies by Reed and Crabill. Crabill (1) reported the isolation of *Trichoderma koningi* Oud. in culture 72 times in 116 trials, using apple roots from seven sources, and concluded that this fungus is probably the cause of rootrot. No experimental proof of its pathogenicity was given. Jensen (9), Werkenthin (13), and Waksman (12) have found *T. koningi* commonly present in various types of soil, and the writers have found it common on decaying wood. Although we have also frequently isolated this fungus from diseased apple roots, we are convinced from inoculation studies that it exists in them as a saprophyte in tissue killed by other agencies.

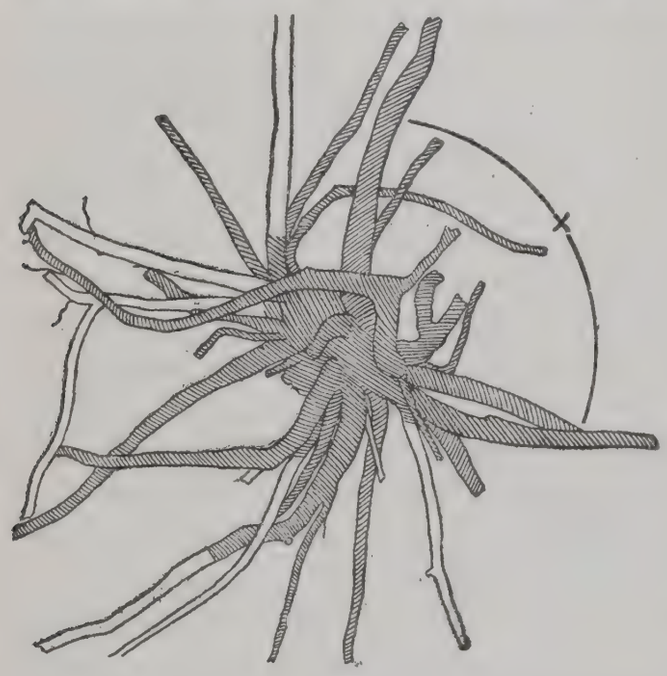

Fig. 1.—Root system of a 7-year-old apple tree affected with rootrot. The infected parts are shaded. Infection was progressing outward on the sound roots. The initial infection probably took place on the side marked *X*. Drawn from a photograph.

In our isolations we have plated fragments of diseased roots on agar media. In the early part of the work the tissue fragments were taken from various parts of roots and a number of species of fungi were obtained, with *Trichoderma koningi* predominating. Later, the fragments were taken only from the margins of the lesions. A considerable number of these have yielded cultures of a species of Xylaria,[1] often uncontaminated with *T. koningi*, the most common accompaniment, and occasional species of Fusarium, unidentified fungi, and bacteria. *Physalospora cydoniae* Arnaud (*Sphaeropsis malorum* Peck) was obtained from the

[1] At first assigned to the genus Stilbella. A culture bearing conidial stromata was submitted to Dr. C. L. Shear, of the Bureau of Plant Industry, who stated that the fungus was probably *Xylaria hypoxylon*.

roots of one tree and from the margin of a trunk lesion extending about 1 foot above the surface of the ground on another. *X. polymorpha* was also obtained from both these sources. An unidentified fungus, probably a basidiomycete, which invests the roots with a conspicuous mat of white mycelium has been cultured from several sources. It has proved slightly, if at all, pathogenic on excised living apple roots in a moist chamber, but its appearance in the field suggests that it may be parasitic in some cases, probably on unthrifty trees.

Cultures of species of Xylaria were obtained during 1915 and 1916 from orchards located at 11 places in Virginia. Three species are represented.

Xylaria hypoxylon has been obtained from nine places: Winchester, Middletown, Pleasant Valley, Staunton, Fishersville, Cloverdale, Blacksburg, Buena Vista, and Greenwood. The isolations from the last two places are tentatively assigned to this species, but differ from the typical *X. hypoxylon* in certain constant cultural features; whether these are of specific or varietal character remains to be determined.

Xylaria polymorpha has been obtained from two orchards at Barber. The identity of the cultures obtained from apple roots has been established by comparison with cultures grown from ascospores taken from mature stromata on apple roots and locust stumps.

Xylaria sp. from Harrisonburg is distinct from the two preceeding species. In culture it resembles *X. cornu-damae* (Schw.) Berk. obtained from germinated ascospores from locust, but its identity with this species is problematical.

CULTURE FEATURES OF THE XYLARIAS

All species of Xylaria grew readily on a variety of nutrient media. Gueguen (6), Harder (8), and Freeman (2) have studied the development of *X. hypoxylon* in culture, and Gueguen (7) has also described pure cultures of *X. polymorpha*. Our experience that stromata of *X. hypoxylon* bearing conidia are produced on a variety of culture media is in agreement with their findings. Freeman, however, states that ascospores were produced in cultures of *X. hypoxylon* on steamed blocks of elm wood in six or eight weeks. We have not succeeded in obtaining ascospores in any of our cultures.

Czapec agar [1] and a starch-agar medium have been used in most of our isolation and culture work, the former being preferable for the production of stromata. The colonies of the three species in petri-dish cultures are easily distinguished. Colonies of *Xylaria hypoxylon* (Pl. 16, *D*) have considerable aerial mycelium with strongly marked, irregularly concentric zones, irregularly lobed margins, and dark pigmentation. Colonies of *X. polymorpha* and *Xylaria* sp. have appressed mycelium with

[1] Cane sugar, 30.0 gm.; magnesium sulphate, 0.5 gm., potasium chlorid, 0.5 gm; potassium acid phosphate, 1.0 gm.; sodium nitrate, 2.0 gm.; iron sulphate, trace; agar, 20.0 gm.; water, 1,000 c. c.

indistinct zonation, entire or slightly lobed margins, and produce pigment only with age or not at all. Colonies of *Xylaria* sp. enlarge much more slowly than those of the two other species. The zonation of colonies of *X. hypoxylon* results from the formation of aerial mycelium at the growing margins followed by appressed mycelium. The pigment, which is at first greenish and becomes almost black with age, forms first in the central zone and appears in the other zones successively from the center outwards. The upright stromata begin to form when the colonies are about 2 weeks old and may appear at the center or on the margins of the zones. They vary in numbers from 2 or 3 to 20 or more. The stromata of *X. hypoxlon* are borne singly or in groups and may become 4 cm. or more in length, with a diameter of 2 or 3 mm. (Pl. 17, *E*). Conidia are produced at the upper extremities in four or five weeks. Cultures of *X. polymorpha* and *Xylaria* sp. have commonly produced only rudimentary stromata. One culture of *X. polymorpha* has, however, developed stromata 5 cm. long and 2 mm. broad. Gueguen's (7) experience that the development of *X. polymorpha* in culture is correlated with its seasonal development in nature is of interest in this connection. A more detailed study of the production of stromata and conidia is reserved for a later publication.

PATHOGENICITY OF THE XYLARIAS

Little is known of the exact mode of life of the Xylarias in nature. It has probably been assumed very generally that they exist as saprophytes; and the appearance of their fructifications on stumps, fence posts, and similar situations is evidence that they are commonly saprophytic. We have found but one reference which bears on the question of parasitism. Harder (8) obtained evidence of the pathogenicity of *X. hypoxylon* when inoculated into small wounds in short pieces of living 1-year-old shoots of two trees (the species were not named). After three months in moist chambers the shoots were still living, as shown by the development of buds and roots, the bark at the point of inoculation was browned to a distance of 3.5 cm., and the wood beneath was brown and dead. The inoculum was recovered.

Our inoculations were made on living apple roots and branches in moist chambers and in the field, also on roots of peach (*Amygdalus persica*), hawthorn (*Crataegus spathulata*), red oak (*Quercus rubra*), white oak (*Q. alba*), and walnut (*Juglans nigra*) in moist chambers.

MOIST-CHAMBER INOCULATIONS

Pieces of roots or branches about 6 inches long and 1 inch in diameter were used. After a preliminary washing and sterilization in alcohol a small notch was cut with a sterile knife and the inoculum of mycelium from the growing margin of a colony introduced. Moisture was main-

tained with a layer of sterilized sand. Roots of apple, peach, hawthorn, and walnut remained alive and in good condition in these moist chambers for more than three months, often sending out shoots several inches long. The oak roots did not keep so well and showed no adventitious budding. One series included inoculations with isolations of *Xylaria hypoxylon* from seven sources and with *Xylaria* sp. Each moist chamber contained one inoculated apple root, one control root wounded but not inoculated, and one inoculated apple limb. All the strains of *X. hypoxylon* proved pathogenic on apple roots and limbs. On roots the progress of infection was seen in the production of surface mycelium on the bark (Pl. 16, *F*) radiating outward from the point of inoculation accompanied by drops of brown exudate and some splitting of the bark. The mycelium, at first white, later developed pigment and formed a black stromatic crust over the surface of the root, typical of that found on affected apple roots in nature. The surface mycelium and crust developed most vigorously in a saturated atmosphere. After six weeks the pieces were removed and split longitudinally through the wound. The bark and wood were brown and dead to some distance from the wound (Pl. 16, *A*). The smallest lesion produced extended 1 cm. and the largest 9 cm. proximally and distally from the point of inoculation. The depth of the lesions varied from 3 mm. to 1.5 cm., sometimes extending to the center of the root. Abundant mycelium was found in the vascular bundles, while but little was present in the medullary rays. All the control roots remained healthy. Additional inoculations have confirmed these results. The inoculum has been recovered with ease whenever attempted.

On limbs the mycelium of *Xylaria hypoxylon* produced more conspicuous surface mats than on the roots (Pl. 16, *B*) and from which the black encrustation developed (Pl. 16, *C*). Six-inch lengths of limbs were completely covered with the mycelium in less than six weeks; the wood, however, was only penetrated to a depth of a few millimeters. *Xylaria* sp. proved almost as vigorous a parasite as *X. hypoxylon*. In 10 weeks the root infection had spread 2 cm. proximally and distally and 5 mm. inward, while that on the limb had advanced 3 cm. in the bark and had penetrated the wood 2 mm.

Xylaria hypoxylon proved only slightly pathogenic on roots of red oak, white oak, and walnut. A heavy black crust was formed over the wound, but the wood was penetrated but slightly after three months. The hawthorn root was attacked somewhat more vigorously, the wood having been penetrated to a distance of 1 cm. in three months.

Mycelium of *Xylaria polymorpha* produced only slight penetration of the bark of apple roots after three months, and similar results were obtained with peach roots. Ascospores sown on the wound surface of an apple root produced a small amount of mycelium which did not penetrate the sound wood.

Trichoderma koningi, when placed on wounded living apple roots in a moist chamber, grew for a time on the medium transferred, but produced no penetration of the root. *Sphaeropsis malorum*, however, proved pathogenic on apple roots, but the infection progressed more slowly than that produced with *Xylaria hypoxylon*. The lesion had extended 1.5 cm. proximally and distally and to a depth of 5 mm. after four weeks (Pl. 15, *E*). Recovery in pure culture was obtained.

FIELD INOCULATIONS

Results similar to those obtained in moist chambers have been obtained in inoculations of living apple roots in the field. A number of 1-year-old apple trees were inoculated with *Xylaria hypoxylon* through a small bark wound near the base of the main root and then planted. A few of these examined after four months all showed infection. One bore a lesion 1.5 cm. long which had penetrated to the center of the root. *X. hypoxylon* was recovered from the margin of the lesion. A number of roots of a 20-year-old apple tree were cut across about 5 feet from the trunk, and mycelium of *X. hypoxylon* was inserted beneath the bark at the cut end. The wound was covered with cotton and the soil replaced. Two of these roots examined after seven weeks had been killed 4 cm. from the wound and bore the typical black encrustations on the surface. Another series of roots were inoculated through small bark wounds. After five weeks infection was well established and was advancing into living tissue.

CONCLUSIONS FROM INOCULATION STUDIES

Xylaria hypoxylon has proved to be an active wound parasite on apple roots; *Xylaria* sp. from Harrisonburg is also a wound parasite, and *X. polymorpha* appears to be only slightly or occasionally parasitic. *Sphaeropsis malorum* is the only other fungus obtained from apple roots that has proven parasitic. The isolation of *X. hypoxylon* from roots of affected trees from 9 of the 11 orchards under observation and the experimental evidence of its pathogenicity, accompanied by the production of symptoms in inoculated roots typical of those found in the orchard, indicate that this fungus is the common cause of the black rootrot of the apple in Virginia. Confirmatory evidence must be obtained in the production of typical symptoms and death in growing apple trees from pure-culture inoculations. This is provided for in a series of 500 young apple trees inoculated and planted during the past year (1916) at Blacksburg. Positive results from these inoculations can not be expected for a year or more, since the disease progresses slowly in nature.

CONTROL OF BLACK ROOTROT

No control measures of proved value are known. There is little possibility of effecting the cure of diseased trees. Those showing but

slight foliage symptoms of rootrot are found to have the infection of the root system so well established that the removal of infected parts from the tree and soil seems a practical impossibility. Control measures must therefore be directed toward the prevention of replant infection and further spread of the infection to healthy trees. Experiments with soil disinfection on a small scale offered but little promise. Replants set after soil treatment with some of the common disinfectants died as rapidly as those on untreated soil. Enough work on this line has not been carried on, however, to warrant general conclusions. Tests of the susceptibility of different rootstocks is suggested as a promising line of experiment.

It has been the practice among some orchardists to lime the soil from which trees affected with rootrot were removed before replanting. We have not secured sufficient data to judge of the value of this treatment, but it seems probable from laboratory studies that an alkaline soil is less favorable for the growth of species of Xylaria than an acid soil. The radius of colonies of *X. hypoxylon* after three weeks' growth on starch-agar media, which ranged in reaction between $-20°$ and $+10°$ Fuller's scale was as follows: $-20°=2.6$ cm.; $-10°=3.0$ cm.; neutral$=$ 3.0 cm.; $+10°=4.5$ cm. Similarly the addition of hydrated lime ($Ca(OH)_2$) to the medium produced a check in the growth of colonies of *X. hypoxylon*, the radius of the colony on the untreated medium at 17 days being 4.0 cm., while that on the medium receiving hydrated lime was 2.5 cm.

Field observations indicate that infection is commonly distributed through the orchard in cultivation. The establishment of quarantined areas, where the disease is confined to limited blocks of trees, and the withholding of cultivation within these areas, thus preventing the carrying over of infective material to the noninfected areas, should prove of value in some cases. The removal of borers without disinfection of the knife may readily transmit infection from diseased to healthy trees. It further seems quite probable that the infection of healthy trees may result from the intermingling of their roots with those of diseased trees, but infection would probably progress slowly in this manner.

The Xylarias are commonly present on stumps of forest trees, and rootrot is consequently most severe on newly cleared land. It seems that the use of cultivated land only for orchard sites may be of considerable practical importance as a preventive measure.

SUMMARY

Black rootrot of the apple is an infectious disease of very considerable economic importance which has become a serious menace in the chief orchard sections of Virginia.

Foliage symptoms of the disease are not markedly different from those produced by injuries due to other agencies, but the black encrustations

on the surface of affected roots and the accompanying dark zonations in the bark and wood are reliable diagnostic features.

Field observations show that rootrot is infectious. The progress of the disease indicates an attack of a comparatively slow working parasite. Two or more years of infection are probably required to produce the death of the tree.

Apple trees planted on newly cleared land are more liable to attack than those on land cleared and cultivated for some time before planting.

Three species of Xylaria have been obtained in pure culture from affected apple roots. *X. hypoxylon* obtained from orchards at nine places proved to be an active wound parasite on living apple roots in moist chambers and in the field. Typical black rootrot symptoms were produced and recovery in pure culture was obtained. *Xylaria* sp. (undetermined) from one source also proved pathogenic. *X. polymorpha* from two orchards at one place proved only slightly, if at all, pathogenic. *X. hypoxylon* is probably the chief cause of black rootrot of the apple in Virginia.

Exclusion practices are suggested as control measures of probable value.

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PLATE 15

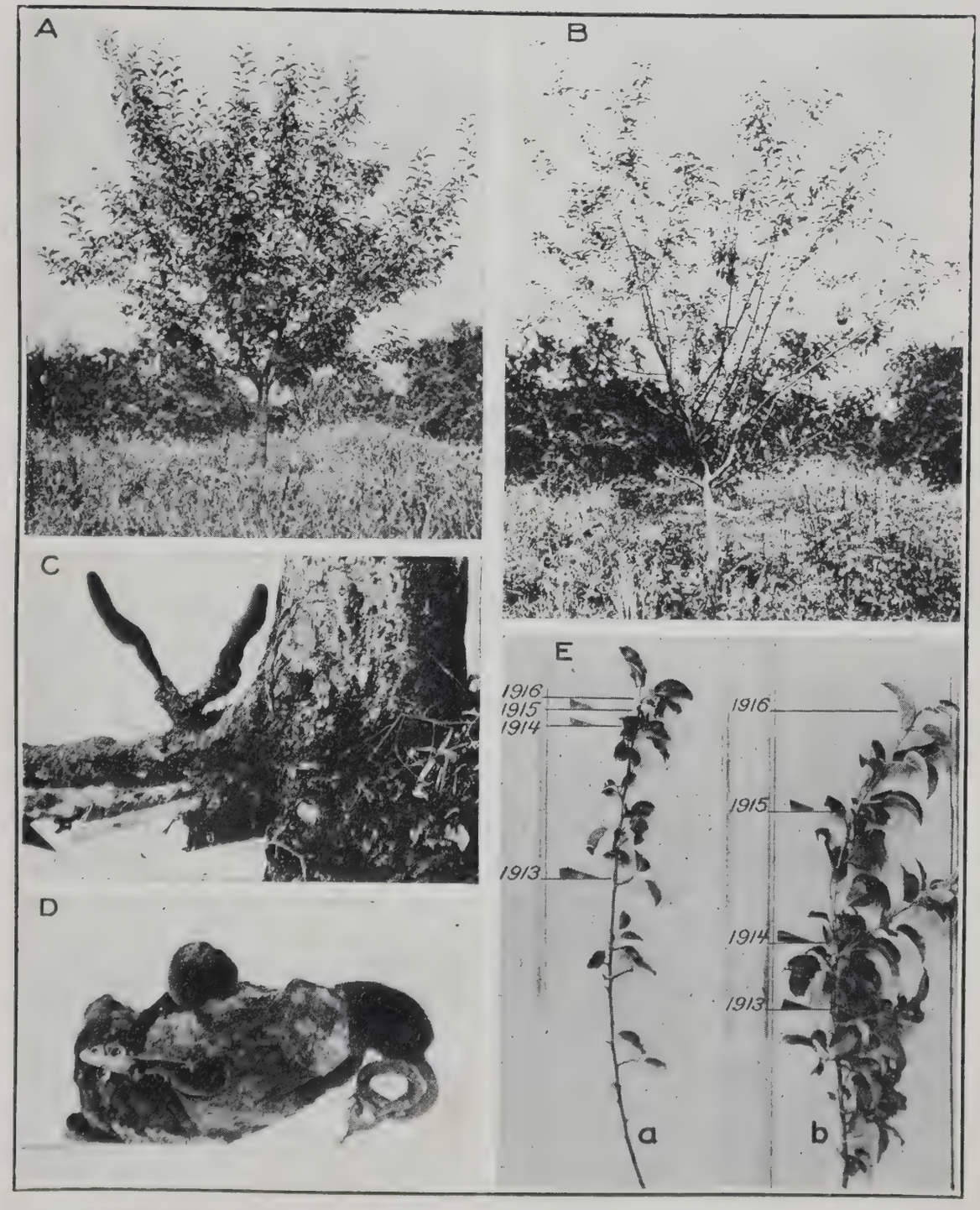
A.—A healthy 6-year-old apple tree contiguous to the affected tree shown in figure *B*, which appears in the background.

B.—A 6-year-old apple tree showing pronounced symptoms of rootrot in the thinness of the foliage and inclination of the trunk.

C.—*Xylaria polymorpha* fruiting on large lateral root of a 7-year-old apple tree.

D.—*Xylaria hypoxylon* developing stromata on an apple root after three months in a moist chamber.

E.—Terminal growths of trees shown in figures A and B, showing effect of rootrot on annual increase in length: *a*, branch from the tree affected by rootrot; *b*, branch from the healthy tree.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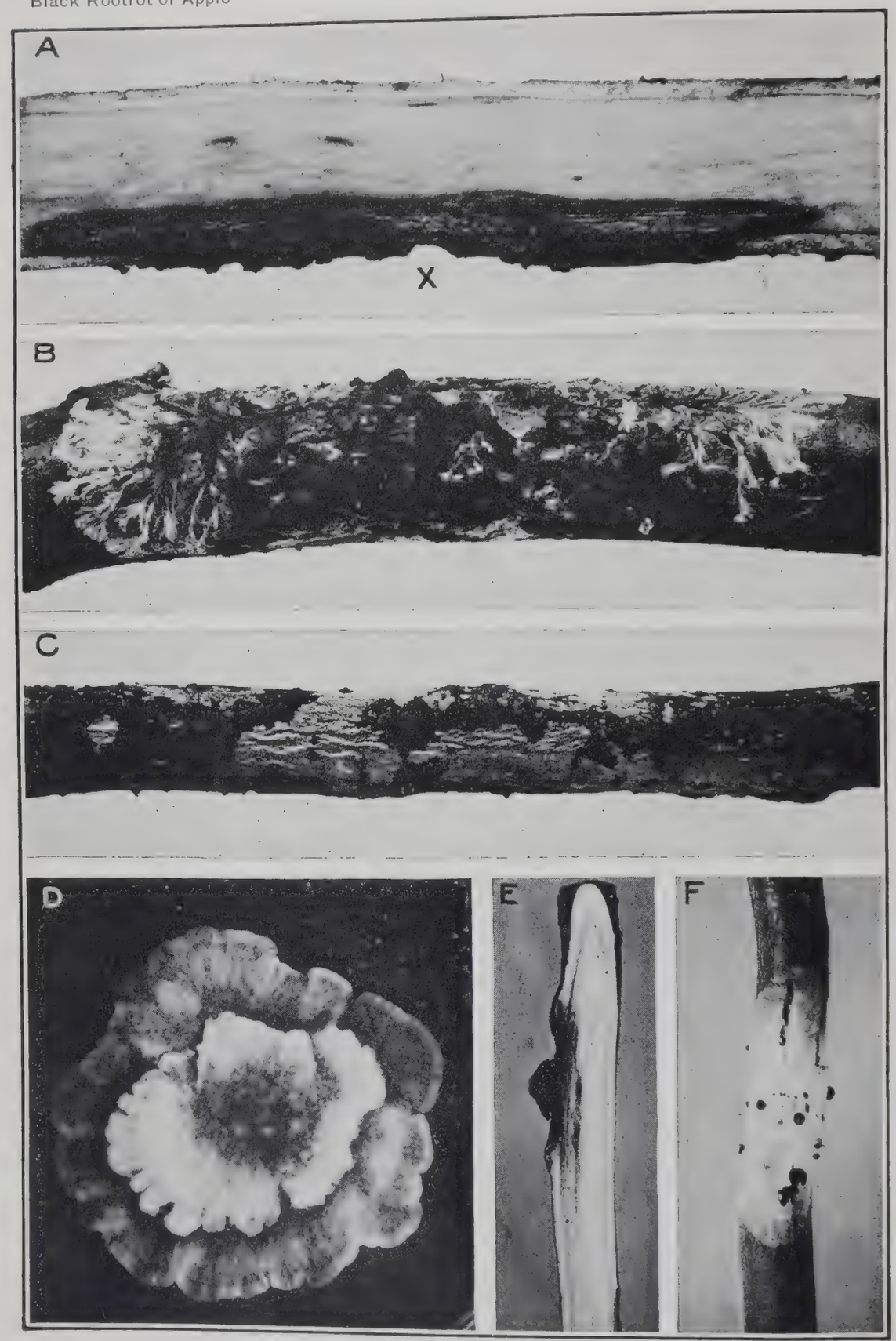

A
X
B
C
D
E
F

PLATE 16

A.—A longitudinal section of a living apple root inoculated at *X* with mycelium of *X. hypoxylon* showing discoloration of wood and bark, after six weeks in a moist chamber.

B.—Surface view of a living apple limb inoculated with *X. hypoxylon* after five weeks in moist chamber.

C.—Black encrustation produced on an apple limb inoculated with *X. hypoxylon* in a moist chamber.

D.—An 8-day old colony of *X. hypoxylon* on starch agar showing characteristic zonation and lobed margin.

E.—A longitudinal section of a living apple root inoculated with *Sphaeropsis malorum*, after four weeks in a moist chamber. A black mat of mycelium has formed over point of inoculation.

F.—A surface view of a living apple root inoculated with mycelium of *X. hypoxylon*, after four weeks in moist chamber.

PLATE 17

A.—*Xylaria hypoxylon* fruiting at the base of a dead apple tree.

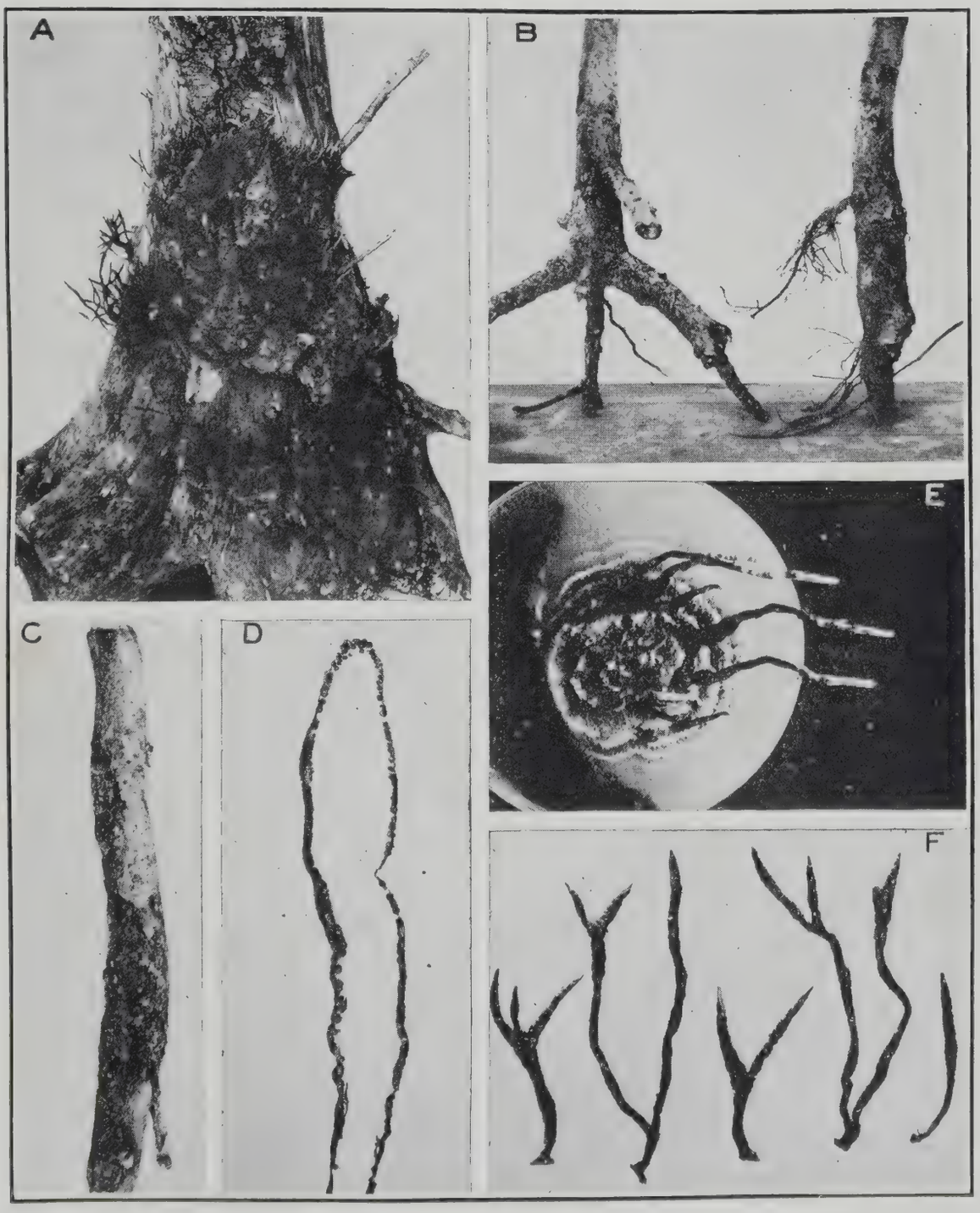
B.—Stumps of young apple trees which have died from rootrot after having been planted where old trees had died from the same cause. Note black encrustations. Photographed by Dr. H. S. Reed.

C.—Black rootrot lesions on an apple root from Cloverdale, Va. The margin between diseased and sound parts is sharply marked. *X. hypoxylon* was obtained from these lesions.

D.—Longitudinal section of a stroma of *X. polymorpha*, showing perithecia embedded in the periphery.

E.—Conidial stromata of *X. hypoxylon* in petri-dish culture on Czapec agar. The direction of growth is positively phototropic.

F.—Mature stromata of *X. hypoxylon* from stump shown in figure A, producing ascospores after one month in a moist chamber.


A
B
C
D
E
F

PHYSIOLOGICAL EFFECT ON GROWTH AND REPRODUCTION OF RATIONS BALANCED FROM RESTRICTED SOURCES

By E. B. HART, E. V. MCCOLLUM, and H. STEENBOCK, *of the Department of Agricultural Chemistry*, and G. C. HUMPHREY, *of the Department of Animal Husbandry, Wisconsin Agricultural Experiment Station*

Our early work (6)[1] on the nutrition of Herbivora with restricted rations demonstrated clearly the inadequacy of the accepted theory as to what constitutes a balanced or complete ration. Up to that time total protein (without reference to quality), energy, and ash materials were considered the essentials of a ration. The latter, however, occupied no position in the mathematical expression of the standards developed. The standards have been stated only in terms of total digestible protein and energy. It is, however, probably true that in a practical sense and with the generally accepted knowledge of the quality of feeding materials accumulated from a long and varied experience, such standards have had and will continue to have very great value; but their limitations are also made evident by this earlier work and are emphasized by what we have since done. Within the past few years our knowledge (1, 2, 7, 9, 10, 13, 16, 17) of the essentials of a ration have expanded, and to-day we would consider a ration complete and efficient only when it contained protein of adequate quantity and quality, adequate energy, ash materials in proper quantity and proportion, and two factors of unknown constitution (vitamines), designated by this laboratory (11) "fat-soluble A" and "water-soluble B."

In addition to the above normal factors, there may be introduced with natural foodstuffs the important factor of toxicity (4, 5, 12). This can be wholly absent or so mild in its effects as to be entirely obscured when the other essentials of a ration are at an optimum adjustment; or with fair adjustment it may only reveal its effects when the ration is continued over a very long time and the animal involved in the extra strains of reproduction and milk secretion. This resistance to toxicity is very materially increased through a proper adjustment of the normal factors of nutrition.

With this recognition of all the normal factors for adequate nutrition there should not arise simultaneously a desire for a mathematical expression of these factors in feeding standards. It is doubtful if this can ever be done, at least for certain of them. For example, the rôle of the mineral nutrients is so varied, including such widely separated functions

[1] Reference is made by number to "Literature cited," p. 197–198.

as construction and control through antagonism as to make it seem futile to attempt an expression of absolute requirements when natural foods, with their diversity of mineral content, are involved. Even the recognition of differences in the quality of proteins and their relation to nutrition (3, 8, 14) will make it more difficult to continue expressing protein requirements in exact quantities than before the development of such knowledge; and what can be said of the quantitative requirements of fat-soluble A and water-soluble B and their supply in feeding materials?

All these developments of the last few years emphasize the need of a thorough study of the contributing nutritive factors of a single foodstuff, and in the state of our present knowledge such information will be secured only by physiological tests involving the animal in reproduction and milk secretion. A contributing factor by a natural food may at times be in the nature of toxicity and this may serve as a harmful and abnormal factor. As such knowledge develops and it becomes clear that this or that single food material will supply adequately the normal nutritive factors not measurable by any quantitative chemical method, such as fat-soluble A, water-soluble B, or mineral nutrients, then we will return with more confidence to the mathematical standard that involves only the energy and protein supply of that single food material. This confidence in the expressed quantities of energy and protein available in a foodstuff will rest upon the definite information that they become physiologically effective only when they form part of a ration which carries one or a number of foodstuffs supplying adequately the other nutritive factors. With such an understanding the feeding standards developed on the energy-protein basis would continue to be theoretically sound and of very great practical value. As illustrative of our position, and taken from our own experience with wheat-grain feeding, we would feel reasonably safe if a wheat-grain ration, based on protein and energy and to be fed continuously to a growing herbivorous animal, was built around alfalfa hay, less safe if built around corn stover, and fearful of disaster should the roughage used be wheat straw. These facts should emphasize the very great necessity for the accumulation of information on the nutritive value of single foodstuffs, and it is apparent that such information will become very valuable in the future use of the protein-energy standards. Such knowledge will not destroy, but will supplement the feeding standards of the present time and secure more confidence in their use.

EXPERIMENTAL WORK

GROWTH ON WHEAT AND CORN RATIONS

For purposes of locating the deficiencies of the all-wheat-plant ration (wheat grain, wheat gluten, and wheat straw), which had given fair growth, but was a failure in reproduction with grade Shorthorn heifers,

a series of experiments was again started in 1910, using for the purpose vigorous grade Holstein heifers of initial weights of from 200 to 400 pounds. It was also proposed that one group should receive its nutrients wholly from the corn plant, another from the wheat plant, a third from corn grain and wheat straw, a fourth from wheat grain and corn stover, and a fifth group should receive its nutrients from corn grain with the roughage equally divided between alfalfa hay and wheat straw. These rations were closely comparable in digestible proteins and net available energy and were "balanced" in the ordinary sense of the standards. The animals were fed what they would consume of this mixture and in addition received common salt and natural water. They were allowed a daily run to an outside paddock free from all vegetation.[1] Their records of growth and final status are given in Table I.

TABLE I.—*Record of growth of Holstein calves, 1910–1912*

No. of animal.	Ration.	Weight (in pounds).					Condition after 2 years.
		Initial (June 2, 1910).	After 6 months on ration.	After 1 year on ration.	After 18 months on ration.	After 2 years on ration.	
629	Ground wheat, 8 pounds; Wheat gluten, 0.3 pounds; Wheat straw, 5.7 pounds	377	655	569	610	452	Miserably emaciated.
639	do	406	722	683	630	519	Do.
637	Wheat grain, 6.7 pounds; Wheat gluten, 0.3 pounds; Corn stover 7 pounds	206	369	533	656	790	Fairly strong.
641	do	207	377	594	783	820	Do.
575	Corn meal, 5 pounds; Gluten feed, 2 pounds; Corn stover, 7 pounds	349	664	970	1,139	974	Strong and vigorous.
594	do	270	496	735	905	923	Do.
635	Corn meal, 5 pounds; Gluten feed, 3 pounds; Wheat straw, 6 pounds	208	301	480	591	690	Poor growth and poor condition.
636	do	220	384	541	684	642	Do.
642	Corn meal, 5 pounds; Gluten feed, 2 pounds; Wheat straw, 3.5 pounds; Alfalfa hay, 3.5 pounds	.....	[a] 613	686	911	1,161	Strong and vigorous.
643	do	.....	[a] 537	602	800	788	Do.

[a] Initial weight.

This breed was more sensitive to the all-wheat ration than our earlier records (6) showed for the Shorthorn cattle, or at least these individuals were. Sustained growth was not possible on this ration. After reaching weights of 600 or 700 pounds both individuals (No. 629 and 639) began to decline in weight and passed into a miserable condition (Pl. 18); they failed to show œstrus and consequently could not be bred. This same group (wheat grain plus wheat straw), if slightly excited or hurried would collapse and remain in a prostrated position for a few minutes, suffering muscular rigor and tremor. From this condition the animals would gradually recover, appearing normal only after a lapse of 10 or

[1] Very great credit is due Mr. William Voss for his constant and intelligent care of these animals.

15 minutes. One of them became blind. The critical factors in this ration were poor mineral content and toxicity. This statement is based on the records made by other animals of this species (to be described later in this paper) and on records with rats and swine (5, 12).

Plates 18 to 22 illustrate the condition of all lots as calves and at the end of two years' feeding.

In contrast to the all-wheat-ration group stood the all-corn-ration group. The latter not only showed continuous growth, but became physiologically active and produced strong calves. The decline in weight at the end of two years shown by No. 575 was due to slow recovery after calving.

When the ration consisted of wheat grain and corn stover, fair but sustained growth was obtained; but it was below normal. The marked improvement made by the use of another roughage, contributing at least as one factor a better mineral content, was most illuminating. These animals showed œstrus and were bred.

When the ration was made from corn grain and wheat straw, slow growth continued for a long time, but the animals were in poor condition. They were better than the wheat-grain and wheat-straw group, since we were able to get one bred, although the other failed to show œstrus. As will be more fully demonstrated later, the critical factor was the mineral content of this ration, and these results serve to emphasize how important a factor the mineral side of a ration becomes in reproduction.

Strong and vigorous individuals resulted where a corn-grain plus wheat-straw plus alfalfa mixture was used. The displacement of half of the wheat straw with alfalfa hay changed the ration from a failure to a success. It might be assumed that the introduction of alfalfa hay corrected the ration by the addition of more or different proteins, but it is more probable that its chief but not only contributing factor in this case was a more efficient ash mixture.

In Table II are recorded the reproduction records of these animals, as well as those of five older cows, reserved from our older herd, the records of which were made public by the writers (6) in 1911. The constituents of the ration fed the older cows were in the same proportions as used for the younger heifers, as shown in Table I. For breeding these animals a Guernsey bull was used in the case of all the old individuals, but a Holstein bull served the 10 Holstein heifers. In addition to the records of birth, there is given in the last column the average daily weight of milk produced for 30 days.

TABLE II.—*Records of reproduction and milk secretion*

CALVES

No. of cow.	Ration.	Sex.	Weight at birth.	Number of days before time of calving.	Condition of calf.	Milk record, daily average for 30 days.
			Pounds.			*Pounds.*
629	All wheat	.....	.....	.....	Cows did not breed.	.....
639	.....do	.....	.....	.....	.....	.....
637	Wheat grain plus corn stover.	Bull....	82	15	Weak, grew strong; peculiar deflection of head.	15.9
641	.....do	Heifer..	65	8	Strong	18.9
575	All corn	Bull....	85	8	.....do	24.8
594	.....do	Heifer..	95	6	.....do	22.7
635	Corn grain plus wheat straw.	.....	.....	.....	Cow did not breed.	.....
636	.....do	Bull....	70	18	Dead at birth.	11.9
642	Corn grain plus wheat straw plus alfalfa.	Heifer..	88	6	Strong	26.0
643	.....do	...do....	71	13	Fairly strong..	27.2

OLDER COWS

562	Corn grain plus wheat straw.	Bull....	47	27	Weak, died ...	18.4
567	.....do	...do....	54	23	.....do	19.9
570	.....do	...do....	68	10	.....do	15.6
563	All corn	Heifer..	65	5	Strong	22.6
572	.....do	Bull....	84	0	.....do	24.4

The splitting of the ration disclosed two things of importance for our understanding. First, that disaster would follow the use of a corn-grain and wheat-straw ration, indicating that the failure of a wheat-grain and wheat-straw ration was partially to be attributed to the straw. The second fact of importance was that a wheat-grain and corn-stover ration was not perfectly complete, giving at times weak offspring and also indicating that the wheat grain was a contributor to the failure of a wheat-grain and wheat-straw ration. In addition to Table II, there are added a number of illustrations (Pl. 23, 24, 25, *A*–*B*) showing the condition of the mothers and the calves at date of birth.

Attention should be called to the peculiar limpness and weakness of calves born on a wheat-grain and corn-stover ration. Occasionally such individuals would be able to get up after birth, nurse, and take care of themselves; but more often they would lie stretched out limp and unable to hold their heads in an upright position and would have died had they not been fed by an attendant. Lying in this prostrated position, the head was often thrown back until it rested against the

shoulder, or when moved, wabbled to the other side, making deflections and contortions not unlike those made by pigeons suffering from polyneuritis. Fed the mother's milk with the continuance of the same ration this condition usually disappeared after two weeks, and the calf continued to grow normally. On this ration (wheat grain plus corn stover) the mothers appeared perfectly normal, although we have no evidence that they were absolutely so. The depressing factor of the ration (probable toxicity of the wheat grain) was having its greatest effect on the offspring and presumably through the placenta. It is an interesting fact that this pathological condition could apparently be cured with the milk of the same mother on the same ration. By the use of the milk from the mother the weakness would gradually disappear, and in two to three weeks some calves if born alive from a cow fed a wheat-grain and corn-stover ration would appear normal, while invariably a calf fed a corn-grain and wheat-straw ration could not be saved. We would have to assume as a logical explanation of the revival of the offspring with the mother's milk that during intrauterine life the placental membrane was traversed by the toxic factor, while the mammary cells were not, or that the milk furnished a more perfect nutritive medium than the blood stream, thereby providing for more effective resistance to the action of the toxic material than a poorer ration could. The latter hypothesis is in our judgment less tenable.

INFLUENCE ON MILK SECRETION AND REPRODUCTION OF SALTS ADDED TO IMPERFECT RATIONS

From analytical data we early recognized that a wheat and wheat-straw ration differed materially in its mineral content from a corn and corn-stover ration (6, p. 138). The bases of these diets (calcium, magnesium, and potassium) were considerably lower in quantity in the wheat ration than in the corn ration. In fact, animals on a wheat ration always produced a urine acid to litmus, while on a corn ration the reaction with the same indicator was alkaline. In 1911 we presented a limited amount of data upon the effect of adding calcium, magnesium, and potassium carbonates to a wheat and wheat-straw ration in such quantities as to make the intake of bases practically identical with their quantity in a corn ration. We have again done this with a number of animals, and in addition have supplied the bases as salts of organic acids. It was believed that there might be some additional disturbance created by the continued use of alkaline carbonates and their tendency to keep the contents of the first portion of the digestive tract in alkaline condition, which might explain our failure to correct the disastrous results with the wheat and wheat-straw ration. Consequently quantities of bases equivalent to those added as carbonates were added as calcium lactate, magnesium citrate, and potassium citrate. In some rations only a single salt, such as calcium lactate or potassium citrate,

was added, in which case the amount was made equivalent in basicity to the basicity of a mixture of the three salts. While, of course, single salt additions did not make the ash of the wheat and wheat-straw ration comparable with that of the corn ration, it did serve to correct its acidity.

We have also stated that failure in reproduction resulted when a corn-grain and wheat-straw ration was used. If our theory was correct, that the main deficiency of this ration was a proper mineral content, then salt additions could be made with normal results; and such was actually the case. In Table III are brought together the records of such studies. The amounts of carbonates added to 14 pounds of the ration were 13 gm. of calcium carbonate, 21 gm. of magnesium carbonate, and 47 gm. of potassium carbonate. In the case of the organic salts we used 40 gm. of calcium lactate [$Ca(C_3H_5O_3)_2+5H_2O$]; 60 gms. of magnesium citrate [$Mg_3(C_6H_5O_7)_2+14H_2O$]; and 80 gm. of potassium citrate ($K_3C_6H_5O_7+H_2O$). When calcium lactate was used alone 232 gm. were added to 14 pounds of the ration; where the salt was magnesium citrate alone 181 gm. were used, and where potassium citrate was the only salt 163 gm. were employed. In Table III the numbers of the cows may appear repeated, owing to the fact that it records several gestation periods of a single individual. In addition to the table, Plate 25, *C–G*, is added to illustrate the condition of both mothers and calves on some of the rations.

TABLE III.—*Records of reproduction and milk secretion*

No. of cow.	Ration.	Sex of calf.	Weight at birth.	Number of days before time of calving.	Condition of calves.	Milk record, average daily yield for 30 days.
			Pounds.			*Pounds.*
645	Wheat plus wheat straw plus inorganic mixture.	Heifer...	74	4	Dead at birth.....	15.9
644	.....do.....	.....	.....	.....	Cow would not breed.	.....
567	Wheat, wheat straw, organic salts.	Bull.....	40	98	Dead at birth.....	(a)
570	.....do.....	Heifer...	72	15	Weak, died at 72 hours.	18.9
646	Corn grain plus wheat straw plus organic salts.	...do.....	75	16	Strong; lived.....	26.21
647	.....do.....	...do.....	72	22	.....do.....	28.2
636	.....do.....	...do.....	83	16	.....do.....	26.6
570	Wheat grain plus wheat straw plus calcium lactate.	.....	.....	.....	Cow would not breed.	.....
562	.....do.....	.....	.....	.....	.....do.....	.....
637	Wheat plus wheat straw plus magnesium citrate.	Bull.....	33	69	Dead at birth.....	(a)
641	.....do.....	...do.....	37	65	.....do.....	(a)

a No milk.

TABLE III.—*Records of reproduction and milk secretion*—Continued.

No. of cow.	Ration.	Sex of calf.	Weight at birth.	Number of days before time of calving.	Condition of calves.	Milk record, average daily yield for 30 days.
			Pounds.			*Pounds.*
645	Wheat grain plus wheat straw plus potassium citrate.	.....	.....	.....	Cow would not breed.	.....
644	.....do.....	.....	.....	.....	.....do.....	.....
636	Wheat grain plus wheat straw plus organic salts.	Heifer...	59	38	Dead at birth.....	(a)
651	.....do.....	Bull.....	54	35	Weak; died.....	11.9
637	Wheat grain plus corn stover.	...do.....	66	26	.....do.....	26
641	.....do.....	...do.....	82	18	Strong; lived.....	25.3

a No milk.

Table III illustrates certain principles very clearly. It shows that it was impossible to make the wheat-grain and wheat-straw ration complete by additions of salts whether they were inorganic or organic in character. Single additions also were a failure and even disturbed in some instances the breeding potency. These records make it clear that an acid condition was not the only disturbing factor of an all-wheat ration, but that there was some other factor at work, resident in the grain. The substitution of the corn grain for the wheat grain made the ration physiologically perfect where, in addition to the straw, certain salt additions were made. The calves produced by the mothers on this latter ration were normal and the milk secretion good. The history of No. 636 is particularly instructive in this connection. As seen in Table II, on a corn-grain and wheat-straw ration her calf was dead and she secreted but 11.9 pounds of milk daily. On a corn-grain plus wheat-straw plus organic-salt mixture (Table III) the calf was born strong, lived, grew up, and was finally sold. On this ration the average daily milk secretion reached 26.6 pounds. Again, on a wheat-grain plus wheat-straw plus organic-salt mixture (Table III) a dead calf was produced by the same cow and little or no milk secreted.

In addition to the records of the effect of additions of a salt there are shown records of No. 637 and 641, again illustrating the effect of adding corn stover to the wheat grain. In the case of one individual, No. 641, a strong calf resulted, while this same cow on the wheat plus wheat-straw plus magnesium-citrate ration produced a dead calf. In the case of the other cow, No. 637, the corn stover did not completely overcome the toxicity of the wheat grain, although it accomplished much more than mere additions of a salt to a wheat-grain and wheat-straw ration could, as evidenced by the greater length of intrauterine life. Illustrations of cows and calves under the influence of these rations are given in Plate

26, *A–C*. With the addition of the organic salts to the wheat-grain and wheat-straw ration the mature mothers remained in apparently good condition for a very long time, as shown in the illustration of No. 570 (Pl. 25, *E–G*).

These records demonstrate clearly that in the wheat-grain and wheat-straw ration at least two factors were operative against normal nutrition: Poor ash and toxicity; but that a corn and wheat-straw ration could be made complete by a suitable ash adjustment, while a wheat and wheat-straw ration could not.

EFFECT ON REPRODUCTION OF BAKING THE WHEAT

The extraordinary facts developed in these inquiries that the whole-wheat grain, unless accompanied by certain roughages, was harmful to growth and reproduction suggested inquiry into the possible effect of baking on these nocuous properties. The fact that baking is always resorted to in the preparation of either bolted-flour bread or whole-wheat bread made this phase of the problem important from the standpoint of human nutrition.

Consequently the grain mixture of the all-wheat ration (wheat grain plus wheat gluten) was sent to a baker, there mixed with water to a dough, molded into loaves, and baked at the usual baking temperature for ordinary white bread. It was then broken up, reground, and fed with wheat straw alone, with straw and organic salts, or with corn stover. In addition to the data on baked wheat, there are also added two records of a medium-grade bolted flour used with corn stover. This flour was of a grade commonly used by the bakers of Madison for bread making. The records of reproduction on these rations are shown in Table IV. Plates 26, *D–F*, and 27 illustrate the condition of the calves and cows receiving these rations.

TABLE IV.—*Record of reproduction and milk secretion with baked wheat and raw flour*

No. of cow.	Ration.	Sex.	Weight at birth.	Number of days before time of calving.	Condition of calf.	Milk record (average daily yield for 30 days).
			Pounds.			*Pounds.*
644	Wheat (baked) plus wheat straw.	Bull....	79	21	Weak (died).....	22.0
645	.....do.....	...do.....	55	35	.....do.....	20.8
647	Wheat (baked) plus wheat straw plus organic salts.	Heifer...	49	27	Weak (died second day).	26.0
649	.....do.....	Bull....	59	33	Weak (died third day).	13.7
650	Wheat (baked) plus corn stover.	He fer...	54	35	Weak (died after 6 days.)	28.8
651	.....do.....	Bull....	83	16	Strong.....	23.0
637	Wheat flour plus corn stover.	...do.....	88	12	Weak (died in 10 minutes).	No milk.
652	.....do.....	Heifer...	87	7	Strong; lived.....	19.6

The data demonstrated that baking had made no improvement in the whole-wheat grain. The toxic substance present was not destroyed or rendered inocuous by the temperature employed. Further, the variation in the resistance of the individual showed itself in the records of Nos. 650 and 651, as they did with Nos. 637 and 641, whose records are shown in Table III. With corn stover as a roughage, the bad effect of the whole-wheat grain disappeared in some cases, but not in all. Attention should be called to the typical attitude taken by most of the wheat-grain calves, illustrated admirably by the calf of No. 644 (Pl. 26, *D–F*). These animals, unable to stand, would lie on their side with their heads thrown back and respiration labored. Feebly blatting, they would often raise their heads to a central position and then let them fall back again upon their shoulders. When raised to their feet, the animals would make no efforts to stand, and if unsupported would fall into a heap. Practically no use was made of the muscles.

Another important fact to be mentioned in this connection is that a cow, after maturity was reached and growth had ceased, could withstand a wheat and wheat-straw ration very much better than during the growing period. This is also illustrated by cow 644 (Pl. 26, *D–F*), an animal that had received this ration for 12 months. Though these animals became slow in movement and sluggish, yet their coats remained fairly bright and smooth, and to all outward appearances appeared normal. The reproduction records with the flour are in harmony with our other records with the ration of wheat grain and corn stover. For some individuals there was apparently some disturbing factor in the flour, which, by the use of a good roughage like corn stover, was overcome, while with other individuals its effect was to disturb reproduction. However, more data should be accumulated on the disturbing factors in wheat flour before final conclusions can be made. For the present, therefore, this phase of the problem is left open.

INFLUENCE ON REPRODUCTION OF SALTS ADDED TO A CORN RATION

While formulating explanations of our failure with the wheat ration, the theory prominent in our minds was the possibility that the disturbances observed were due to an unfavorable balance of mineral materials or a decidedly acid condition in the animal brought about by a low base supply in the ration. If these were real causal agents, then it should be possible to take a ration known to be physiologically adequate and disturb it by additions of bases or acids, thereby presenting to the cells a new relation of these substances. On this theory it was proposed to add to an all-corn ration such proportions of calcium, magnesium, and potassium as would disturb the relation of base to acid radicals and which, in an all-corn-plant ration, were manifestly adequate for successful growth and reproduction.

Consequently we imposed upon the normal corn ration a mixture of either the carbonates or the organic salts of the bases in the same quantitative make-up as was used with the wheat and wheat-straw ration. The quantity used for 14 pounds of the ration was also identical with that imposed upon a wheat-grain and wheat-straw ration described in an earlier part of this paper, and consisted of 13 gm. of calcium carbonate, 21 gm. of magnesium carbonate, and 51 gm. of potassium carbonate. The proportion of organic salts added was 40 gm. of calcium lactate, 60 gm. of magnesium citrate, and 80 gm. of potassium citrate.

This quantity of bases imposed on a corn ration was arbitrarily chosen, but was probably sufficient in quantity to test adequately the theory proposed. In some cases only magnesium salts were added, but in quantities equivalent to the basicity of the mixture of salts used. There has been suggested many times in both fields of plant and animal nutrition that the relation of calcium to magnesium must be rather definitely proportioned if optimum growth is to be expected. For different plants different calcium-magnesium ratios have been proposed as most favorable, although the entire theory, at least in some of its quantitative aspects, is at present on trial. In animal nutrition it has been suggested that disturbances may arise through an excess of magnesium to calcium in the ration. For example, miller's disease of horses is attributed to the use of wheat bran, and especially to the fact that bran contains an excess of magnesium to calcium. The problem of antagonism of elements and salts is an important one for both plant and animal nutrition, but how far regulating mechanisms at cell surfaces in both plants and animals come into play must always be considered before we adopt the idea of the necessity for optimum behavior of a quantitative relation of the ions or molecules. In the all-corn ration calcium oxid and magnesium oxid stood approximately in the relation of 1 to 1. In the wheat and wheat-straw ration the same relation existed. For purposes of orientation we have imposed upon the corn ration magnesium salts (181 gm. of magnesium citrate per 14 pounds), which would make the calcium-magnesium relation approximately 1 to 2

In Table V these records are shown.

98975°—17——3

TABLE V.—*Records of reproduction and milk secretion showing influence of additions of salts to an all-corn ration*

No. of cow.	Ration.	Sex.	Weight at birth.	Number of days before time of calving.	Condition of calf.	Milk record (average daily yield for 30 days).
			Pounds.			*Pounds.*
642	Corn ration plus organic salts.	Bull....	75	10	Fairly strong.....	28.0
650	.....do.....	Heifer...	72	5	Strong; lived.....	19.9
575	Corn ration plus carbonates.	Bull....	92	3	.....do.....	28.2
594	.....do.....	...do....	108	On time	.....do.....	30.7
647	Corn ration plus magnesium citrate.	Heifer...	87	6	.....do.....	34.9
649	.....do.....	Bull....	97	8	.....do.....	25.8

There were no disturbances of an otherwise satisfactory ration by the use of the salts in the quantities here imposed. Even magnesium additions did not disturb reproduction. It is apparent that a considerable range of mineral elements, both as to quantity and quality, may be used in animal nutrition without disturbances, but just what these ranges are must be left for future investigation. It should be recalled that a corn-grain and wheat-straw ration was made efficient by salt additions alone, which would imply that the quantity of base-forming salts in that ration was too low. Milk secretion was also undisturbed by these extra additions of salt to a corn ration. Plate 28 illustrates the effect of these rations on both cows and calves.

INFLUENCE ON REPRODUCTION OF MINERAL ACIDS ADDED TO A CORN RATION

It has been stated that a wheat and wheat-straw ration was of acid character, the urine reacting acid to litmus. For purposes of thorough acquaintance with the influence of such acidity on an otherwise good ration, we added to an all-corn ration daily during gestation such quantities of phosphoric and sulphuric acids as would make the relation of acids to bases approximately similar to that in a wheat and wheat-straw ration. For this purpose there were added to 14 pounds of the all-corn ration 30 c. c. (1.88 sp. gr.) of phosphoric acid and 16 c. c. (1.84 sp. gr.) of sulphuric acid. After dilution with water these were stirred into the corn stover daily, giving it an acid taste not unlike silage. There was no trouble in the continued consumption of this ration. On this diet the urine reacted acid to litmus and showed from 19 to 24 per cent of the nitrogen of the urine as ammoniacal nitrogen, while on an all-corn ration the percentage of nitrogen in the urine as ammonia nitrogen varied from 1.4 to 3.1 per cent of the total nitrogen, and in addition the urine was alkaline to litmus.

That we were accomplishing our purpose of creating an acid ration was apparent; and further, it was clear that this class of animals could aid in maintaining tissue neutrality by the production of ammonia (15).

The records of reproduction are displayed in Table VI.

TABLE VI.—*Records of reproduction and milk secretion on a corn ration plus mineral acids*

No. of cow.	Ration.	Sex.	Weight at birth.	Number of days before time of calving.	Condition of calf.	Milk record (average daily yield for 30 days).
			Pounds.			*Pounds.*
563	Corn ration plus mineral acids.	Bull.....	83	4	Strong.....	19. 1
572	.....do.....	...do.....	78	5	Fairly strong.....	20. 1
563	.....do.....	Heifer...	73	2	Strong.....	19. 9
648	.....do.....	...do.....	77	11	Weak; died.....	23. 9

The results are not entirely harmonious; but in three of the four cases the reproduction was normal, the calves were strong, and they suckled the mother shortly after birth and lived. All of the mothers remained in excellent condition, and we are probably justified in concluding that strong, vigorous mothers would not have reproduction disturbed by an acidity of a ration comparable with that used in this work, provided the ration was otherwise complete. No. 648 did produce a weak calf. This calf made no effort to suckle the mother, could not stand alone, but nevertheless showed none of the head or neck deflections so characteristic of calves produced by wheat-fed mothers. These cows showed no inability to remove the afterbirth, a condition always likely to arise with the premature births on wheat plus wheat-straw rations, unless salt additions had been made. Under the latter circumstances the calf generally would not be carried any nearer to the normal time than where salts were omitted and would either be dead or weak, but the afterbirth would come away normally. This observation is of importance to veterinarians, and the relation of salts in the diet to processes involved in parturition should receive more study.

Illustrations of both calf and mother fed the corn and mineral-acid mixture are shown in Plate 29, *A–B*.

RELATION OF "VITAMINES" TO THE NUTRITION PROBLEM

The discovery that there are at least two essential factors of unknown constitution, both necessary in a ration for growth and probably for reproduction, raised the question as to their relation to these disturbances on an all-wheat-plant ration. As previously stated, these two factors have been designated as "fat-soluble A" and "water-soluble B." We are unquestionably safe in stating that there was a sufficient supply of water-soluble B in our ration of whole wheat plus wheat straw. This

substance is abundantly supplied by the wheat embryo, which constitutes about 5 per cent of the weight of the grain. Fat-soluble A is probably not so abundant in the seeds nor in the particular grain used here—wheat—and for that reason its relation to the problem was given special attention.

The fact that the wheat-grain and corn-stover ration was one giving mixed results, the offspring sometimes being weak and sometimes strong, depending upon the stamina of the mother, suggested its use as one on which the animal could be sensitized. If failure in reproduction should result in a number of cases when butter fat, a good carrier of fat-soluble A, was added to a wheat-grain and corn-stover ration, we would be justified in the conclusion that other factors besides a supply of fat-soluble A and poor ash were at work in causing disaster on a wheat and wheat-straw ration. Consequently butter fat was added to a ration of wheat grain and corn stover at the rate of 2 pounds per hundred of grain. The ration consisted of 6.7 pounds of wheat grain; 0.3 pound of wheat gluten, and 7 pounds of corn stover.

The records of the results on this ration are shown in Table VII.

TABLE VII.—*Records of influence of "vitamines" on reproduction and milk secretion with wheat ration*

No. of cow.	Ration.	Sex.	Weight at birth.	Number of days before time of calving.	Condition of calf.	Milk record. Average daily yield for 30 days.
			Pounds.			*Pounds.*
642	Wheat grain plus corn stover plus butter fat.	Bull.....	44	46	Weak; lived 10 hours.	30.8
653	.....do.....	...do.....	85	13	Strong; lived.....	33.9
653	.....do.....	Heifer....	87	2	Weak; grew strong.	33.0

The data on this phase of the subject support the view that lack of fat-soluble A was not the casual factor in the disturbances recorded. No. 642 on an all-corn and organic-salt ration had produced a strong calf, but on this ration the calf was weak and died (Table VII). The case of No. 653 is interesting and exceedingly important. In her first gestation period on this ration the calf was strong and lived, indicating that the ration was so much improved by the salt additions, through the better roughage used, and a more abundant supply of fat-soluble A as to make possible a successful resistance to the real factor, the toxicity of the wheat kernel.

But this toxicity was apparently cumulative, and in the second gestation period made its effect apparent on the offspring. The calf blatted like a wheat and wheat-straw calf, a weak sort of noise, different from the blat of a normal calf, and would lie flat on the floor, with the head

thrown back, an attitude already described as characteristic for wheat-grain and wheat-straw offspring. On being fed its mother's milk it slowly improved, the symptoms described disappeared, and the animal after one week appeared normal; but only after five days from birth was it able to suckle its mother without help and would have died had it not been given special attention. At the end of two weeks it appeared normal. Plates 29, *C–E*, and 30, *A*, *B*, illustrate the condition of the animals on these rations.

EFFECT OF WHEAT EMBRYO ON REPRODUCTION

It was important that further dissection of the wheat grain be made with the hope of locating in what portion of the kernel toxicity was most prominent. While some data are presented indicating the possibility of toxicity in the flour part of the grain, the work with the embryo makes it clear that it is at least one of the important carriers of toxicity where the whole wheat grain is involved. We have shown that a corn ration was not readily disturbed by moderate shifts in either its bases or acids. Consequently, for purposes of studying the effect of the embryo on reproduction, a basal corn ration was used. We reasoned that should disturbances now arise they could be attributed directly to the imposed wheat embryo. The ration used consisted of seven parts of corn stover, four parts of cornstarch, and three parts of wheat embryo. This ration would introduce from seven to eight times the mass of embryo carried by 8 pounds of whole-wheat meal. In Table VIII the results of wheat-embryo feeding are shown.

TABLE VIII.—*Records of reproduction and milk secretion on wheat embryo*

No. of cow.	Ration.	Sex.	Weight at birth.	Number of days before time of calving.	Condition of calf.	Milk record. Average daily yield for 30 days.
			Pounds.			
562	Cornstarch plus corn stover plus wheat embryo.	Heifer....	24	69	Dead at birth....	No milk.
563	.....do.....	...do.....	32	59	.....do.....	Do.

It is apparent that superimposing the embryo on a good ration, like the corn ration, will bring about early abortion. To all outward appearances the mothers remained in excellent condition, but the calves were notably immature in development and were born over two months ahead of time. We can find no other explanation for these results than that the wheat embryo carried some toxic substance or substances responsible for disturbed growth and reproduction, a result confirmed by the work with swine and rats (4, 5, 12). In Plate 30, *C–D*, the status of one of the mothers and one of the offspring is shown. Note the splendid

condition of the cow. It is apparent that the mature mother may maintain splendid condition, at least for a long time, on a ration which will exhibit its limitations only with the offspring.

CORRECTIVES FOR WHOLE-WHEAT FEEDING WITH THIS CLASS OF ANIMALS

We have made it clear that additions of salt alone will not overcome the toxicity of the wheat-grain and wheat-straw ration. The introduction of corn stover in place of the straw was successful with certain individuals, but often failed with others. By its substitution for the wheat straw the salt mixture was improved, probably a little different protein mixture introduced, and possibly more of fat-soluble A, although it is certain that this change from wheat straw to corn stover did not introduce sufficient of the factors necessary for continued normal nutrition. Our tentative assumption is that the toxicity can be overcome only when either its mass is reduced or there is introduced with a wheat and wheat-straw ration a better protein mixture, a better salt mixture, and an abundance of fat-soluble A. This hypothesis is borne out by the following facts: By substituting casein for the wheat gluten in the ration, thereby shifting the nature of the protein intake and improving its character, both cows, 594 and 654 produced in 1915 strong, vigorous calves weighing 80 and 73 pounds, respectively. The ration consisted of 6.7 pounds of wheat grain, 0.3 pound of casein, and 7 pounds of corn stover. The average daily milk secretion of these animals was 24.6 and 26 pounds, respectively. Plate 30, *E*, shows the condition of No. 654 and her calf of 73 pounds.

When, however, improvement was attempted by additions of only salt and casein, with the straw left in the ration, disaster followed and the calves were either born dead or were weak and died later. This ration consisted of 8.0 pounds of wheat grain, 0.3 pound of casein, 5.7 pounds of wheat straw, and the organic-salt mixture.

In this ration there was a slightly greater amount of toxicity introduced by using a larger proportion of wheat grain, and presumably the straw was contributing but small amounts of fat-soluble A. On this ration cow 655 produced a heifer calf weighing but 49 pounds at birth, 49 days ahead of time and dead, and No. 658 had a male calf of 74 pounds' weight, also dead at birth.

We have, however, had successful results when a part of the wheat straw was displaced by alfalfa hay. Such an addition would theoretically improve the ration through the introduction of a better salt mixture, a different and more efficient protein aggregate, and more of fat-soluble A. These records with alfalfa are shown in Table IX. In addition to the records with wheat grain plus wheat straw plus alfalfa, there are also included records with corn grain plus wheat straw plus alfalfa. The wheat-alfalfa ration consisted of 8 pounds of wheat grain, 0.3 pound of wheat gluten, 2.9 pounds of wheat straw, and 2.9 pounds of alfalfa hay.

The corn-alfalfa ration consisted of 5 pounds of corn grain, 2 pounds of gluten feed, 3 pounds of wheat straw, 3 pounds of alfalfa.

TABLE IX.—*Records of reproduction and milk secretion on a wheat-alfalfa ration*

No. of cow.	Ration.	Sex.	Weight at birth.	Number of days before time of calving.	Condition of calves.	Milk record (average daily yield for 30 days).
			Pounds.			*Pounds.*
642	Corn grain plus wheat straw plus alfalfa.	Heifer...	88	6	Strong; lived.....	26.0
643	.....do.....	...do.....	71	13	.....do.....	27.2
642	.....do.....	...do.....	98	5	.....do.....	35.8
643	.....do.....	...do.....	86	11	.....do.....	39.6
636	Wheat grain plus wheat straw plus alfalfa.	...do.....	61	41	Fairly strong; lived.	No milk.
648	.....do.....	Bull.....	95	1	Strong; lived.....	21.6
648	.....do.....	...do.....	83	2	Fairly strong; lived.	35.0

These records with corn plus wheat straw plus alfalfa show how perfect the ration becomes through the introduction of a natural food material which carries a better mineral content, as illustrated by the substitution of alfalfa hay, with a high mineral content, for wheat straw, with its low mineral supply.

Where the wheat-grain and alfalfa ration was used, the first gestation was fairly successful. Both calves were strong and would have lived independent of the attendant's care. The front legs of the calf of No. 636 were weak.

In the second gestation period, however, the calf of No. 648 was particularly weak in the forelegs and for a period of two to three weeks stood on the first joints. The calf was also blind. It gradually grew strong, but remained permanently blind. This is another illustration of the cumulative effect of the toxicity of the wheat grain. It explains how successfully one may use the whole wheat in a ration carrying a good roughage, or even in such cases how failure may result if the individual mothers are not vigorous and strong or the wheat grain continued in successive gestation periods. It further illustrates the principle that the corrective agents introduced by the alfalfa were better ash, a different and slightly higher protein level, and more of fat-soluble A; it illustrates and emphasizes what profound influences the proper adjustment of the normal factors of nutrition may have on the well-being and the increased resisting powers of the individual even in the presence of the abnormal factor toxicity. Plates 31, and 32, *A–D*, illustrate the results with both corn plus wheat-straw plus alfalfa, and wheat plus wheat-straw plus alfalfa rations.

While failure in reproduction resulted when the ration consisted of corn starch, corn stover, and wheat embryo, it was possible to secure normal offspring when the starch was reduced in quantity and corn meal substituted. On a ration consisting of four parts of corn meal, one part of corn starch, two parts of wheat embryo, and seven parts of corn stover the offspring were apparently normal for the first gestation period. This shows the remarkable supplementary or "antidotal" effect of the corn meal. The mass of embryo in 8 pounds of wheat meal, if we are to attribute all of the deleterious effects on reproduction to the embryo it contains, is about 0.4 pound, and this was the amount that developed disaster in reproduction where wheat was used as the only grain. But in the presence of corn meal at least five times that amount could be used without noticeable disturbance in reproduction, at least in a single gestation. Plate 32, *E*, illustrates this result.

GENERAL DISCUSSION OF RESULTS

We should first like to emphasize the fact that all individuals whose records are involved in this discussion were free from contagious abortion. The herd had been under the observation of Dr. F. B. Hadley, professor of veterinary science in the Experiment Station, during the entire period of experimentation.

In our attempts to locate the trouble in the all-wheat ration (wheat grain plus wheat straw) we have fed rations made up of corn grain and wheat straw. Here the offspring were weak and were often born dead. When to that same ration, however, a suitable salt mixture was added, so that the ash content of the ration was like that of the all-corn ration, perfect offspring resulted. This would clearly indicate that one of the deficiencies of an all-wheat-plant ration was a proper salt mixture. When, however, the corn grain in the above ration was displaced by the wheat grain and the ration consisted of wheat grain plus wheat straw and salts, disaster again resulted, which showed the presence of another disturbing factor in the wheat grain. Calves born by mothers upon this ration showed peculiar deflections of the head, inability to get up and suckle the mother, and in most cases have died within a few hours after birth.

These experiments indicate that in the all-wheat-plant ration there were two factors operative against normal nutrition—namely, a poor salt mixture and inherent toxicity of the wheat grain. When the wheat grain was coupled with corn stover, we have sometimes met with success and sometimes with failure in the character of the offspring. With strong mothers it appears that the corn stover may become an "antidote" and thereby furnish sufficient of all the normal factors of nutrition so as to enable the animal to reproduce normally.

The possibility of destroying the toxicity by heat was also investigated, and baked wheat was fed with corn stover. This had no effect whatever in improving the wheat kernel.

In other cases the wheat-grain and corn-stover ration had butter fat added to it for the purpose of supplying plentifully the growth-promoting factor, fat-soluble A, now known to be necessary for growth and supplied abundantly in butter fat. It was thought possible that the wheat-grain and wheat-straw ration was somewhat deficient in this material. Additions of butter fat, however, did not uniformly improve the ration. We had a number of failures in reproduction, and also a number of successes with its use. This would again emphasize the probability of the presence of a toxic substance in the wheat grain.

When, however, the wheat grain was mixed with a legume hay, such as alfalfa, so that the latter formed but 20 per cent of the ration, we have had perfect success in all cases in the production of normal offspring, at least for the first gestation. The improvement resulting from the use of the alfalfa must lie in introducing in the ration a better salt mixture, perhaps a better protein mixture, and an abundance of growth-promoting substances, all of which may contribute toward making it possible for the cell to destroy or resist the action of the toxic substance introduced. However, in the second-gestation period on the same ration (wheat grain plus wheat straw plus alfalfa hay) the calves were weak, and in one case blind, but it lived. This is extremely interesting as illustrating the cumulative effect of this toxicity.

Where corn stover was wholly substituted for the wheat straw, we had a number of successes and also a number of failures in the first gestation period. Apparently as an "antidote" to the toxicity this roughage was not as effective as the legume hay.

We had thought it possible in our earlier work that the acidity of the wheat ration was an important factor in the results recorded. It was true that the urine of the all-wheat-plant-fed animals showed a slight acidity to litmus, owing to a low intake of bases in the ration. . If this were an important factor in our results, then the successful corn ration might be disturbed with acids and give us results similar to the wheat ration. This, however, we found not to be the case, for when to an all-corn ration there were added mineral acids such as sulphuric and phosphoric acids in such proportions as to make the acidity of the urine of a degree similar to that of a wheat and wheat-straw-fed animal, the offspring were strong and normal in every respect. Even the addition of a high proportion of magnesium salts to a corn ration did not disturb in any way its power of producing normal offspring.

The results detailed above indicate clearly that wheat grain contains a toxic material, and later work has shown that this is very prominent in the embryo of the seed. When wheat embryo is imposed on corn stover so as to bring into the ration seven to eight times the amount of em-

bryo that would be introduced when feeding whole wheat, the result is likely to be an early abortion. The calf is now dropped at six to eight months; this demonstrates that the increased mass of the toxic material produces this disturbance at a somewhat more rapid rate.

This result was particularly likely to occur where no other grain was used with the embryo. With both corn meal and corn stover in the ration the detrimental effect of the wheat embryo was nullified, at least for a single gestation period.

It is an interesting fact that in the wheat milling industry the embryo passes into wheat bran in small amounts but in much greater quantities in wheat middlings. The wheat flour that is used for bread making has the least content of embryo of any of the wheat by-products.

In an attempt to obtain an anatomical picture of the condition responsible for the physiological disturbances as already described, Dr. Bunting, of the medical school of the University of Wisconsin, kindly consented to make a histological study of the tissues from a number of the abnormal calves. In general, no striking lesions were revealed. Livers and kidneys showed some degeneration (hydropic) changes, but the nervous tissues gave the most evidence of the presence of an excessive amount of fluid, a condition of edema. This histological picture was analogous to that of beriberi, the result of feeding polished rice, and it also simulated, if it was not identical, with that obtained from the spinal cord of pigs on certain rations as described in a previous publication (5). The edema was observed between the membranes covering the cord, around the blood vessels, and around the nerve cells. In these instances the nerve cell and their nuclei were shrunken, the latter staining more intensely than normally. No abnormalities in medullation of the fibers of the cord as demonstrable by the Weigert stain were observed. While the observations did not point to anything especially characteristic, it is probable that the motor disturbances observed in the animals can be referred to the edematous condition of the nervous tissues.

The cause of beriberi is ascribed to the absence or deficiency of certain essential factors in the diet, particularly to water-soluble B. In the case of excessive wheat feeding it would appear that the essential causal factor for disaster to growth and reproduction is a toxic substance which either interferes with the utilization of materials necessary for the full development of the nervous system of the animal or directly with the normal functioning of this tissue. This would account for the blindness observed in some of the heifers and also for the failure of muscular coordination apparent in the new-born calves produced on rations of large whole-wheat content.

It was also apparent that rations producing an early delivery of offspring would usually lead to a failure of the animal to remove properly the afterbirth, with its attending dangers of infection; and an

overabundance of a material like wheat straw in a ration, owing to its low salt content, becomes an important factor in premature birth.

An observation in our experimental work of interest to veterinarians was the low resistance to other diseases of the mothers fed the wheat ration. In an outbreak of anthrax in the university herd the only losses to occur from this diease in our experimental herd were among the wheat-grain fed animals.

The principle (5, 12) laid down as to what factors must be present in a ration of natural origin in order that it become efficient for both growth and reproduction is well supported by these data. This principle postulates that there must be present efficient proteins, adequate energy, proper salt mixture, fat-soluble A and water-soluble B (vitamines) and an absence of toxicity, or a toxicity of such mildness as to become inocuous in the presence of the other normal factors of nutrition. The presence of toxicity in the wheat kernel as the explanatory factor for these records rests not only upon the evidence secured with swine and rats but also on that presented here. It is not a deficiency phenomenon. A corn-grain and corn-stover ration is physiologically adequate, while a wheat-grain and corn-stover ration often failed not only when used alone but when there was added to it the most likely limiting factor, fat-soluble A, as butter fat.

The recognition of these normal factors of nutrition and the further recognition of the occurrence in apparently normal foodstuffs of substances of mild toxicity will be of immense advantage in arriving at an understanding of the oft-reported troubles with farm animals, which to-day are either not understood or their etiology is wrongly assigned; and in the field of human nutrition the same principles will apply.

When a few years ago the corn crop of Nebraska failed to mature because of drought, and early rains had produced a bumper wheat crop, it left many farmers with little to feed their breeding stock but wheat grain and certain roughages. In many cases where this was done the calves were born either dead or weak, with great financial losses to many breeders. No one would have suspected that the ration was a factor in these disasters, but it undoubtedly was the direct cause of the trouble.

When Dakota farmers, with their only roughage as wheat straw, try to build up an aninal-husbandry industry, there is likely to arise trouble in reproduction with this class of animals, unless other roughages with better salt mixtures are brought into the ration. We are informed that there is already much trouble with reproduction by cows in the Dakotas wherever much wheat straw is fed. Such facts as these must emphasize the importance of an understanding of all the factors of animal nutrition and in addition an understanding of all the factors contributed by any particular foodstuff. It should further emphasize how such studies can furnish the facts which will aid the animal feeder in avoiding the danger zones of his art. We need more effort placed on the accu-

mulation of information on the physiological behavior of feeding stuffs than on the attempts to bring out new mathematical expressions of feeding standards.

These experiments further show the limitations of the theory of a "balanced" ration as now expressed and indicate the very great importance of other factors besides protein and energy in the successful diet. It was indeed surprising to find that the common wheat kernel had a low toxicity; but such factors as toxicity, growth-promoting substances of unknown nature, proper balance of salts, indicate how complex the problems of animal nutrition really are and how necessary it is that these factors be clearly exposed in order that we may place the various feeds in their proper category. We have pointed out how a material of low toxicity, such as the wheat kernel, may be used with success. A good roughage like a legume hay was an admirable "antidote." Even corn meal and a poorer roughage like corn stover served to offset the detrimental effects of a large mass of wheat embryo. This also illustrates how an adjustment of the normal factors of nutrition may conceal the presence of the detrimental factors.

It is important to keep constantly in mind that the disclosure of either a nutritive deficiency or the presence of an abnormal factor in a common natural foodstuff should not necessarily condemn its use. It should, however, emphasize the need of combining it in the ration with those other natural products which will either supply abundantly the deficiencies or act as an "antidote" to any inherent toxicity.

SUMMARY

This paper summarizes the results of further studies of the physiological value of restricted rations. The data presented are limited to observations on growing and reproducing heifers and are especially concerned with the effect of the nutrients from the wheat and corn plants.

Restriction to the wheat plant as a source of "balanced" nutrients (wheat grain plus wheat straw) did not sustain growth with Holstein heifers. Such animals also failed to show œstrus and could not be bred.

Marked pathological conditions resulted, such as blindness, feeble and emaciated condition, and abnormal excitability followed by collapse. Evidence is presented which fixes the responsibility for such a condition on two factors in the ration: (1) poor salt mixture and (2) inherent toxicity in the grain.

Improvement of the ration could not be made by additions of salt alone.

By the use of corn stover as a roughage in place of the wheat straw, growth was sustained but reproduction was only partially successful, dependent upon the stamina of the mother. Where reproduction was

successful in the first gestation period, it failed in the second, owing to the cumulative effect of the wheat toxicity.

By the use of alfalfa hay to take the place of one-half of the wheat straw, results similar to those with corn stover were secured. Growth was splendid, reproduction normal in the first gestation period, but weakness appeared in the second gestation. The alfalfa and corn stover introduced a better salt mixture, a little different protein mixture, and probably a more plentiful supply of growth-promoting substances, all of which, according to our hypothesis, would either individually or collectively improve the ration, but not necessarily make it perfect. It might still fail if the mass of toxicity was too large.

Baking the wheat grain did not improve it.

The particular effect of these all-wheat-grain rations was to cause marked histological changes in the nervous tissue of the offspring. The motor cells partly degenerated and the spinal cord showed more or less edematous condition. This was analogous to our observations on swine with wheat-grain feeding. On wheat-grain and wheat-straw rations growing heifers also showed symptoms of nerve degeneration, as evidenced by blindness and great excitability. The causes of the disturbance were due to the inherent toxicity of the wheat grain and not to "deficiencies of vitamines."

Corn grain plus wheat straw allowed sustained growth, but at a slow rate. The offspring were weak or dead. Additions of salt to this ration made it normal, indicating that this was the only factor needed for perfect nutrition with this ration.

A physiologically complete ration such as the corn-grain and corn-stover mixture could not be disturbed, at least in a single gestation, by altering the calcium-magnesium ratio through the addition of magnesium salts. Even the addition of mineral acids to this ration, in such quantities as to make the urine of the individuals receiving it acid to litmus and rich in ammonium salts, did not disturb its nutritive completeness.

The addition, however, of wheat embryo to a corn ration did cause disturbances, bringing about early abortions. This was due to its high content of the toxic material of the wheat kernel.

Considerations of the influence of such investigations on practice are also presented.

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PLATE 18

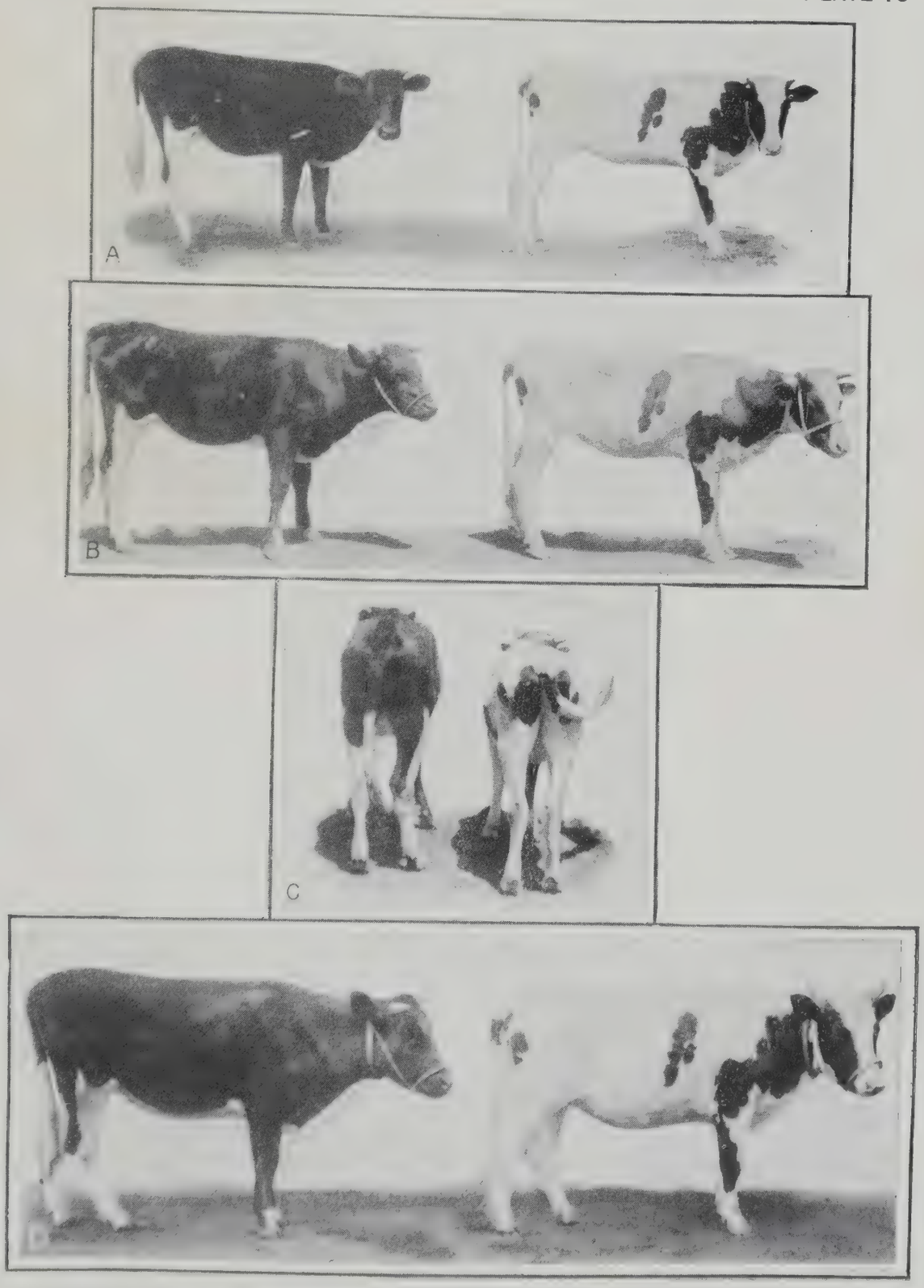
Cattle showing the effect of a ration of wheat grain and wheat straw:

A.—Condition at the initiation of the experiment. June, 1910.

B.—Condition after 12 months on the ration. Note the sluggish and sleepy condition. June, 1911.

C.—Condition after 12 months on the ration. Note the distinct emaciation. June, 1911.

D.—Condition of two yearlings after 18 months on the ration. Both are in sluggish condition and one of them is blind. December, 1911.


A
B
C
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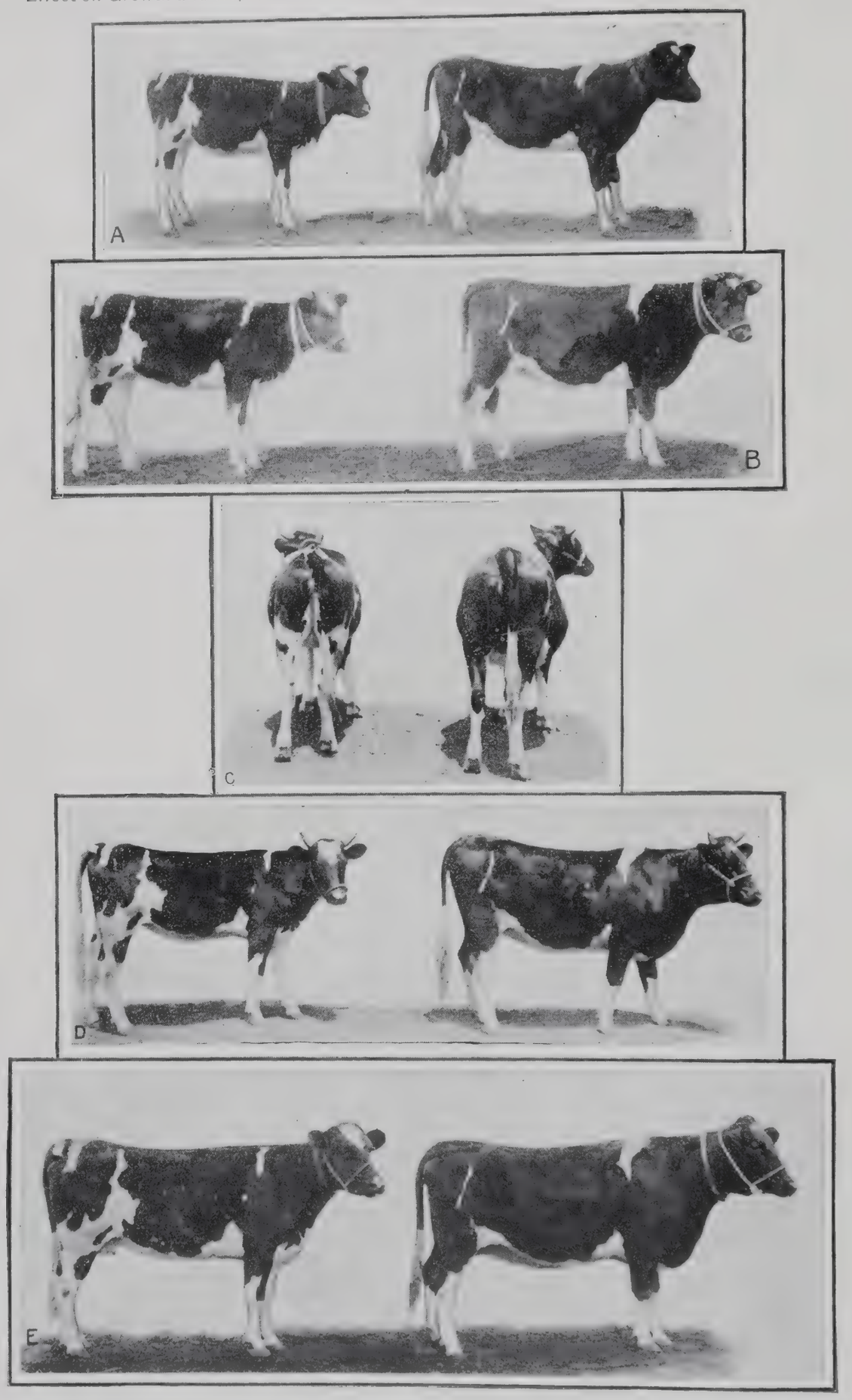
A
B
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PLATE 19

Cattle showing the effect of a ration of corn grain and corn stover:

A.—Condition at the initiation of the experiment. June, 1910.

B.—Condition after 12 months on the ration. Note the alert and thrifty condition. June, 1911.

C–D.—Condition after 12 months on the ration. June, 1911.

E.—Condition after 30 months on the ration. Note the splendid condition. November, 1912.

98975°—17——4

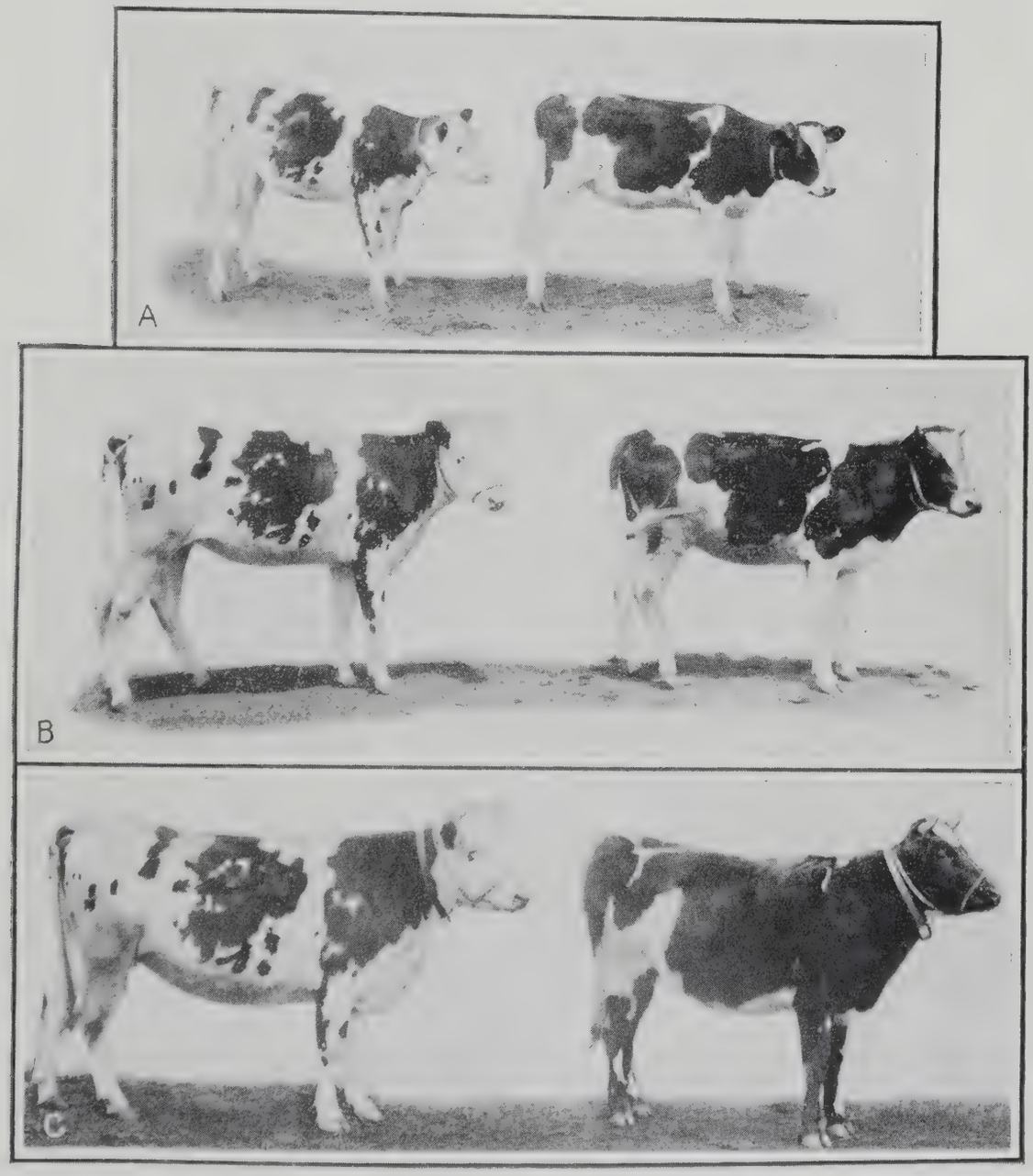
PLATE 20

Cattle showing the effect of a ration of corn grain and wheat straw:

A.—Condition at the initiation of the experiment. June, 1910.

B.—Condition after 12 months on the ration. Note the rather poor condition of these individuals; poor growth had resulted. June, 1911.

C.—Condition after 30 months on the ration. Poor growth had been made and only a fair condition maintained. December, 1912.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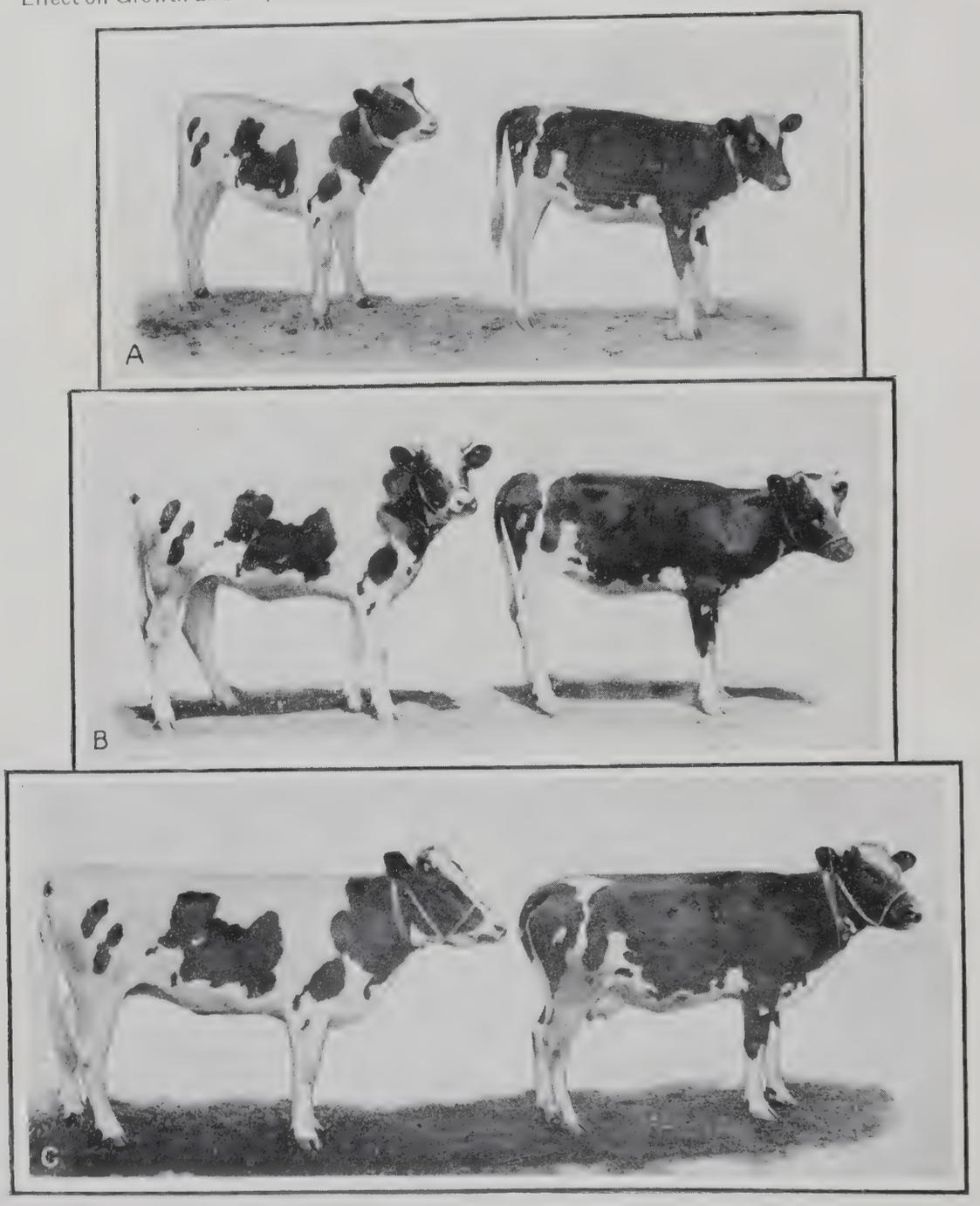
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PLATE 21

Cattle showing the effect of a ration of wheat grain and corn stover:

A.—Condition at the initiation of the experiment. June, 1910.

B.—Condition after 12 months on the ration. Growth was below normal, although the animals were in fair condition. June, 1911.

C.—Condition after 30 months on the ration. Growth below normal. Condition only fair. November, 1912.

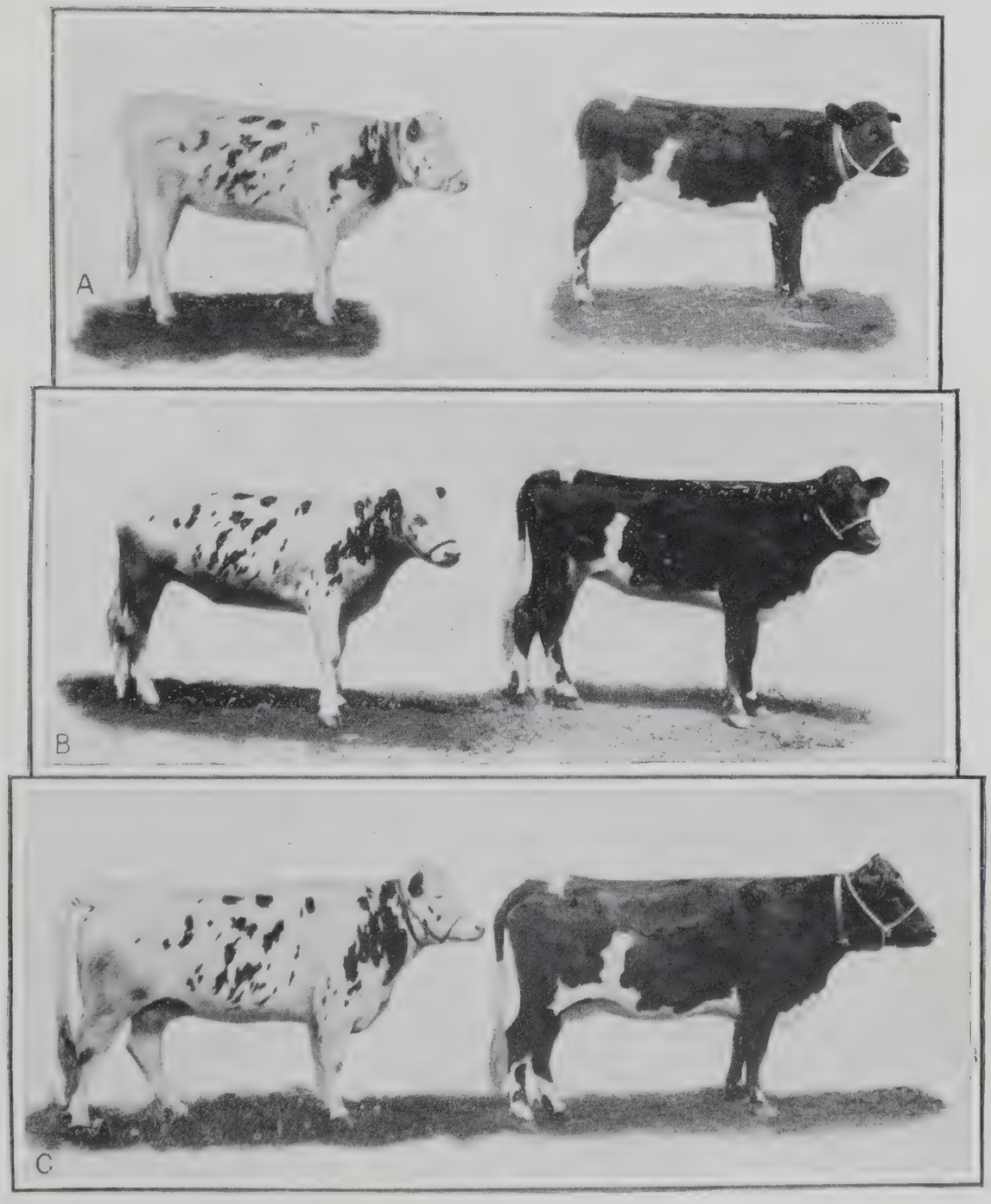
PLATE 22

Cattle showing the effect of a ration of corn grain, wheat straw, and alfalfa:

A.—Condition at the initiation of the experiment. November, 1910.

B.—Condition after 6 months on the ration. In good condition and growing well. June, 1911.

C.—Condition after 24 months on the ration. In splendid condition. November, 1912.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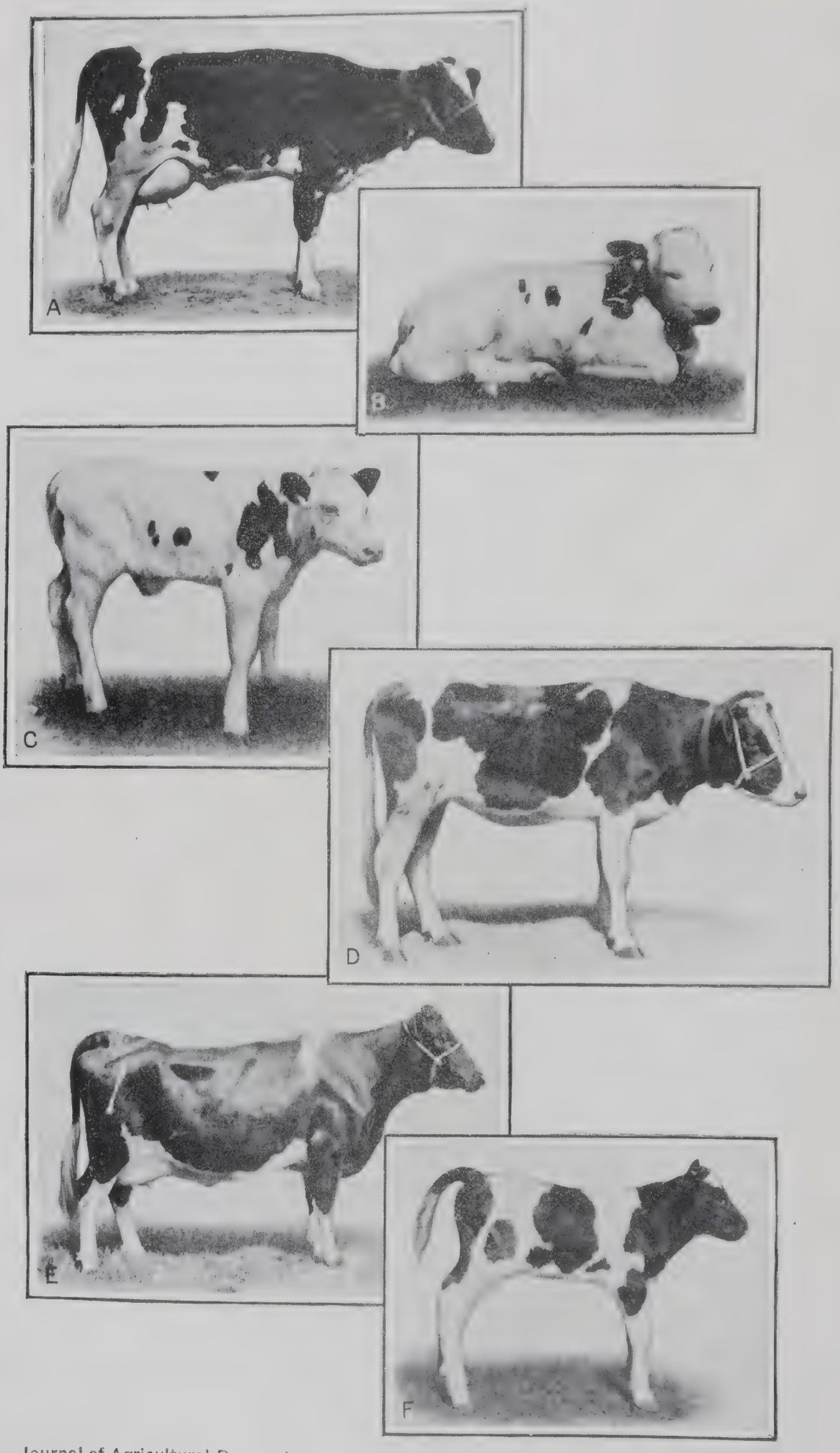
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PLATE 23

Cattle showing the effect of a ration of wheat grain and corn stover:

A–C.—*A*, Mother (No. 637) in poor condition. *B*, Calf weak with peculiar attitude of head. *C*, Calf grew strong.

D.—A heifer (No. 635) showing the effect of a ration of corn grain and wheat straw after 24 months. Note the sleepy and unthrifty condition. She would not breed.

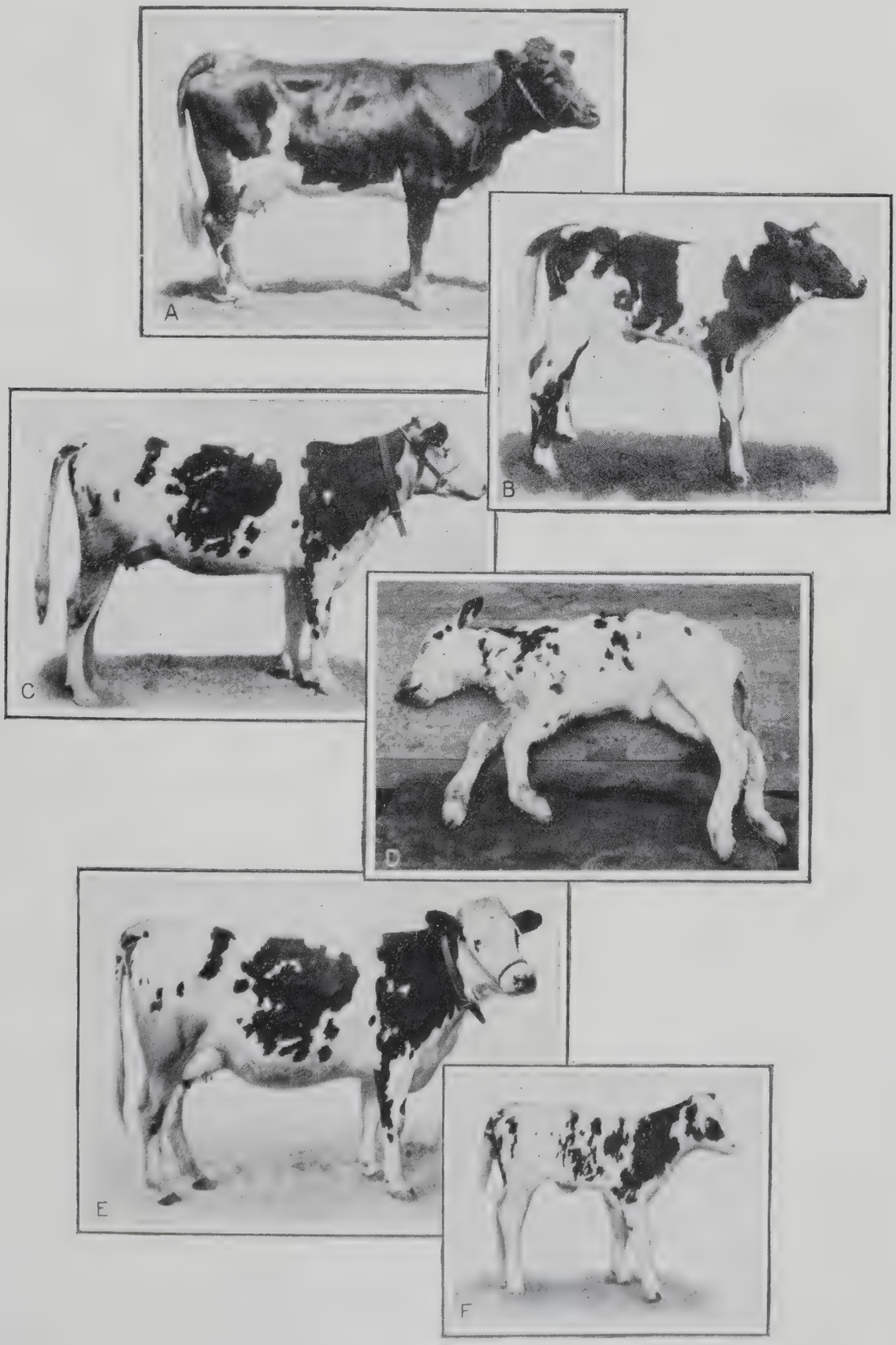
E–F.—A cow (No. 575) and her calf, showing the effect of an all-corn-plant ration after 24 months. They were in splendid condition.

PLATE 24

A–B.—A cow (No. 642) and her calf, showing the effect of a ration of corn grain, wheat straw, and alfalfa hay. The addition of the alfalfa made growth possible and reproduction normal.

C–D.—A cow (No. 636) and her calf, showing the effect of a ration of corn grain and wheat straw. The result of a poor salt mixture. Growth was fair, but the mother was in poor condition and dead offspring resulted.

E–F.—A cow (No. 636) and her calf, showing the effect of a ration of corn grain, wheat straw, and organic salts. By the addition of the salts the mother's condition not only improved, but normal calves resulted.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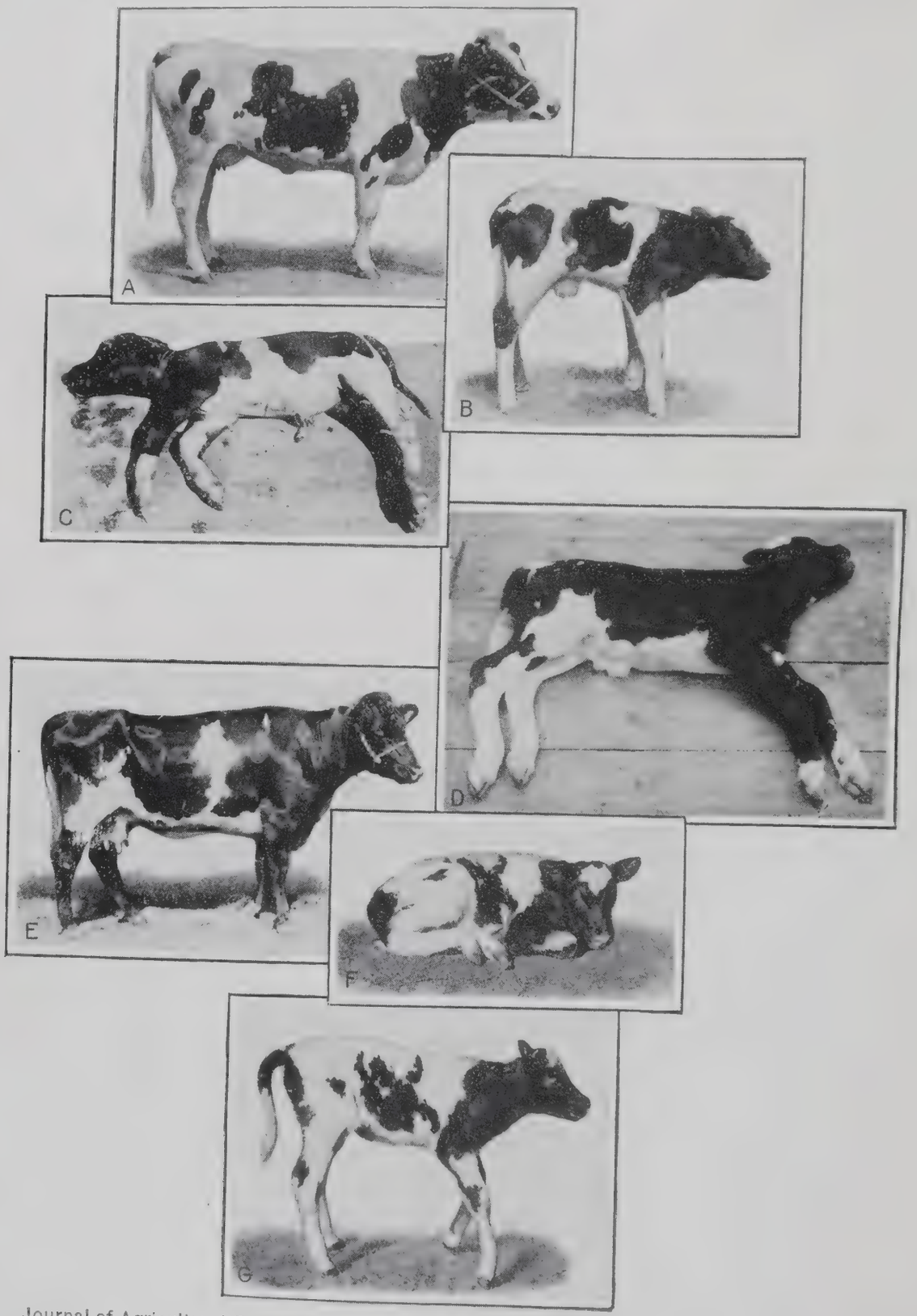
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PLATE 25

A–B.—A cow (No. 641) and her calf, showing the effect of a wheat grain and corn-stover ration. The mother was in fair condition and the offspring was fairly strong. Contrast with Plate 23, *A*, *B*. This indicates how this roughage (corn stover) in some cases adequately supplements the wheat grain, but was not successful with all individuals.

C.—The calf of cow 641, showing the effect of a ration of wheat grain, wheat straw, and magnesium citrate. An illstration of an unsuccessful attempt to improve the wheat ration with a magnesium salt. In no case could it be done. The calf was dead and immature.

D.—The calf of cow 651, showing the effect of a wheat-grain, wheat-straw, and organic-salt mixture. No mixture of salts alone made the ration a normal one for reproduction. This calf was born 35 days ahead of time, weak, and died soon after birth. Note the tendency to throw the head back, a characteristic attitude taken by such animals when alive.

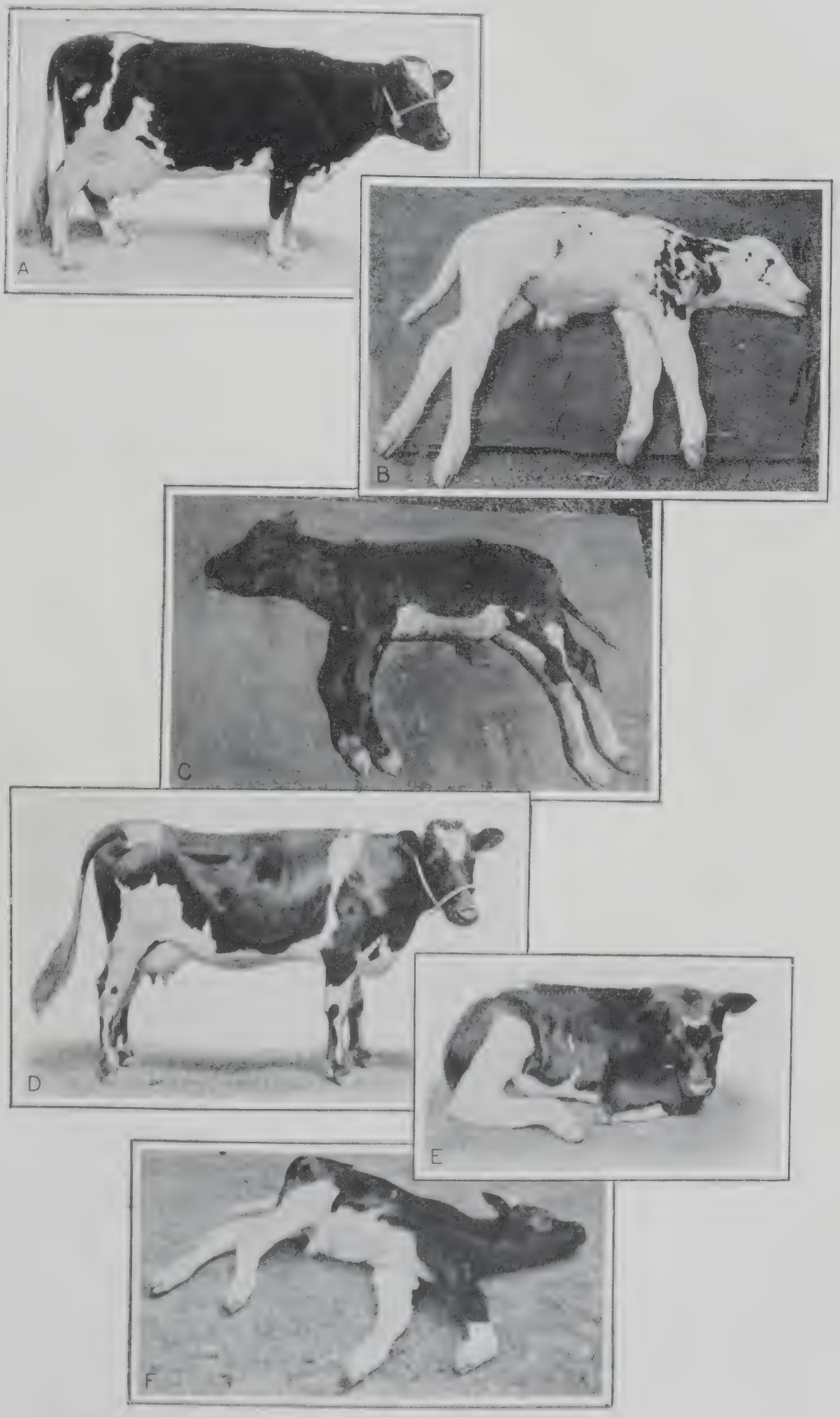
E–G.—A cow (No. 570) and her calf, showing the effect of a wheat-grain, wheat-straw, and organic-salt mixture. This shows the possibility of maintaining the mother in apparently fair condition by additions of a salt, but dead or weak offspring result. This calf lived three days. It had a peculiar blat, entirely unlike normal calves.

PLATE 26

A–B.—A cow (No. 637) and her calf, showing the effect of a wheat-grain and corn-stover ration. Another illustration of the impossibility of general success with corn stover as a supplement to the wheat grain. The mother appeared in good condition, but the offspring was dead.

C.—The calf of cow 636, showing the effect of a wheat-grain, wheat-straw, and organic-salt mixture. The toxicity of the wheat grain could not be overcome by the salt mixture alone. Contrast with Plate 24, *E*, *F*, where the same cow received the same ration, with corn grain instead of wheat grain.

D–F.—A cow (No. 644), showing the effect of a ration of baked wheat and wheat straw. The mother was in fair condition. The calf was alive when photographed, but was weak and could not stand. Note the deflection of the head, a characteristic posture when lying flat, as shown in figure E. The calf died. Baking had not improved the grain.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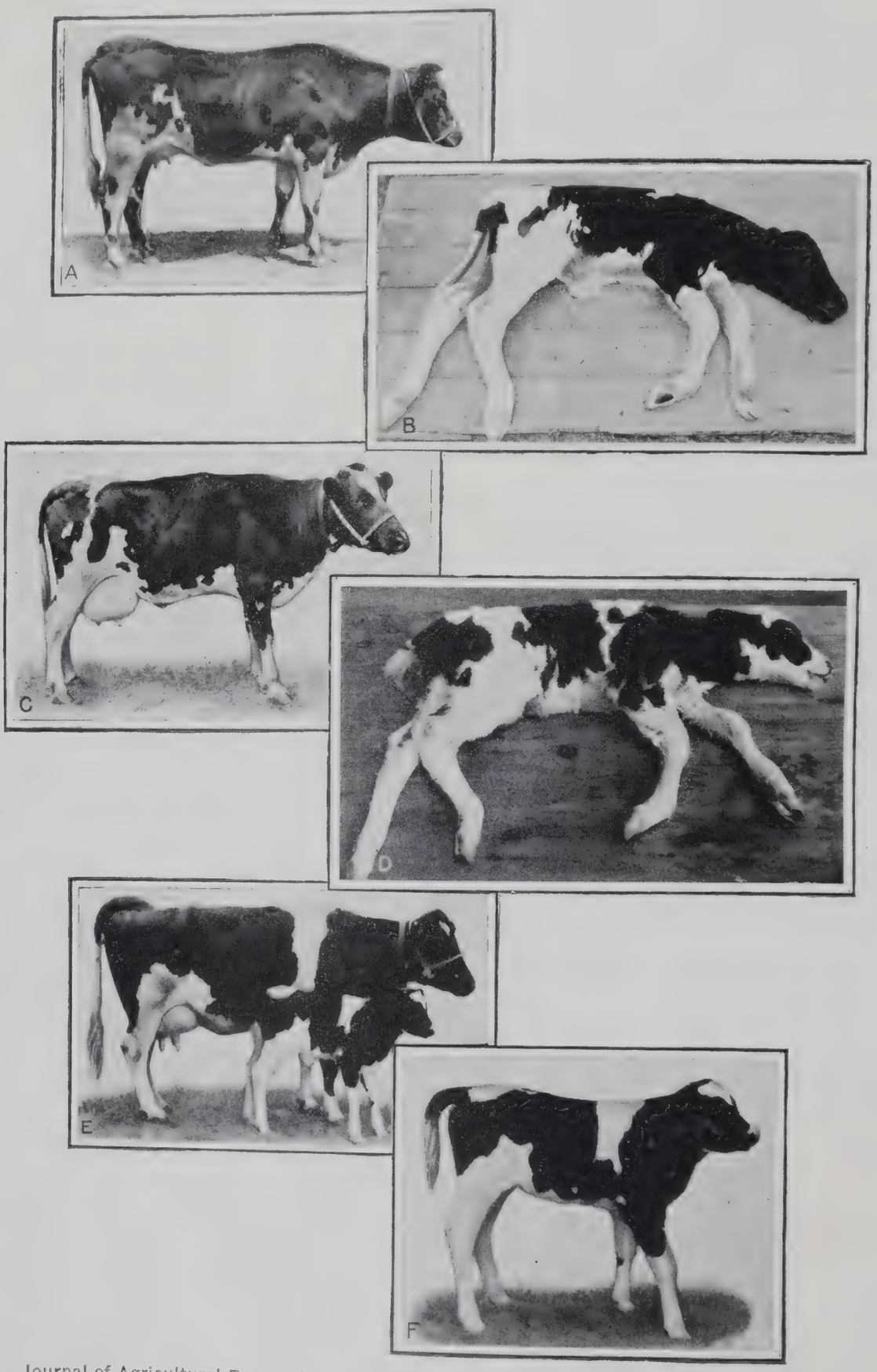
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PLATE 27

A–B.—A cow (No. 645) and her calf, showing the effect of a baked-wheat, wheat-straw, and organic-salt mixture. The calf was dead at birth. Baking and salt additions had not made the ration a perfect one.

C–D.—A cow (No. 637) and her calf, showing the effect of wheat-flour and corn-stover ration. With this cow this ration was unsuccessful for reproduction.

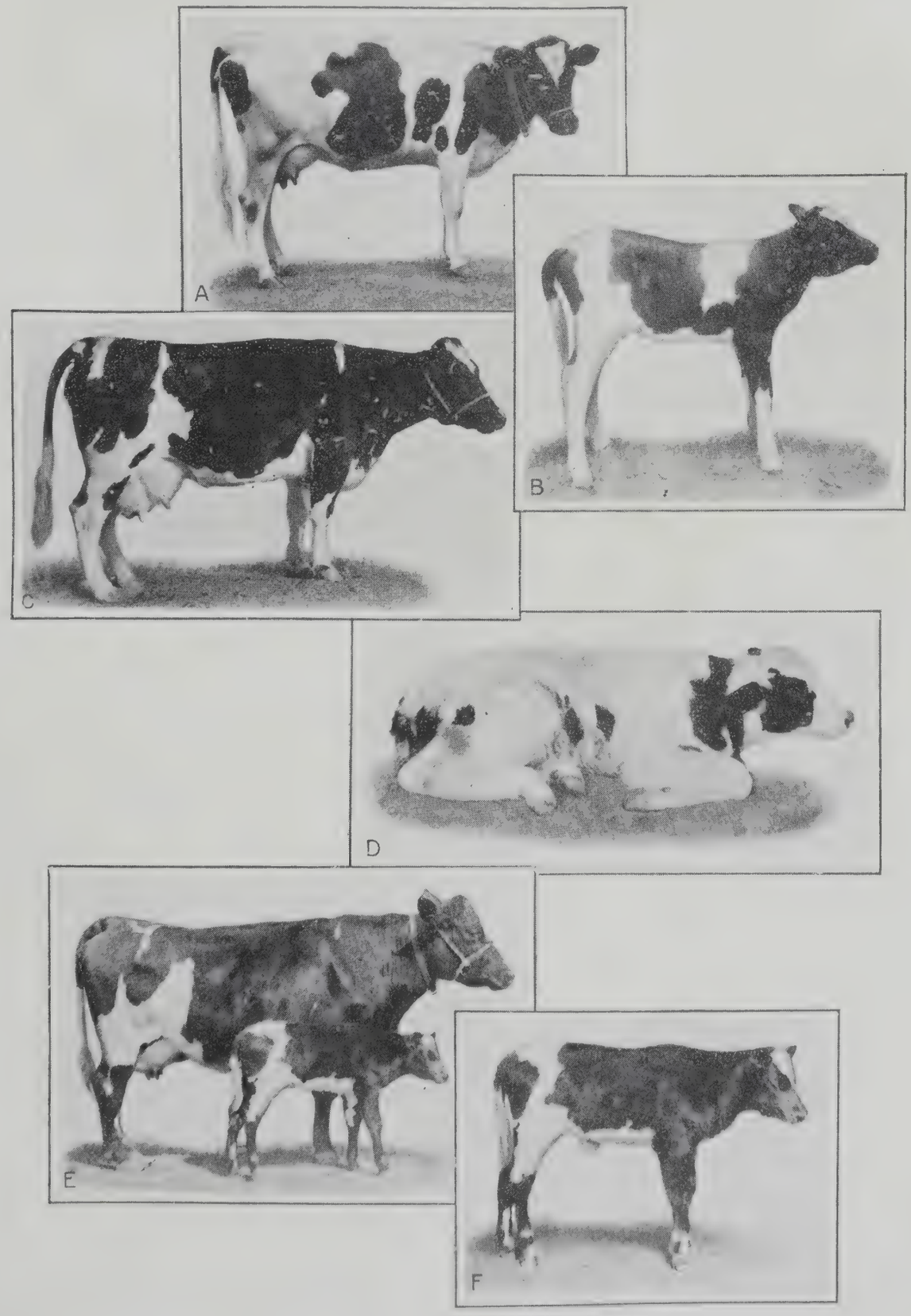
E–F.—A cow (No. 652) and her calf, showing the effect of a wheat-flour and corn-stover ration. With this cow this ration was successful in reproduction. These figures illustrate the differences in individual resistance and make it probable that even wheat flour carries some toxicity, which could not be successfully overcome by corn stover, at least with all individuals.

PLATE 28

A–B.—A cow (No. 650) and her calf, showing the effect of a ration of corn grain, corn stover, and organic salts. The physiological soundness of an all-corn plantation was not disturbed by altering the relation of base and acid radicles. Both calf and mother appeared perfectly normal.

C–D. A cow (No. 594) and her calf, showing the effect of a ration of corn grain, corn stover, and a mixture of inorganic bases as carbonates. The calf was strong and weighed 108 pounds when born. The efficiency of the ration was not destroyed by a change in the relation of bases to acids.

E–F.—A cow (No. 647) and her calf, showing the effect of a ration of corn grain, corn stover, and magnesium citrate. Even additions of magnesium salts alone in quantities sufficient to make the ratio of calcium to magnesium 1 to 2 did not destroy the efficiency for reproduction of an otherwise good ration. The mother and calf were strong and apparently normal.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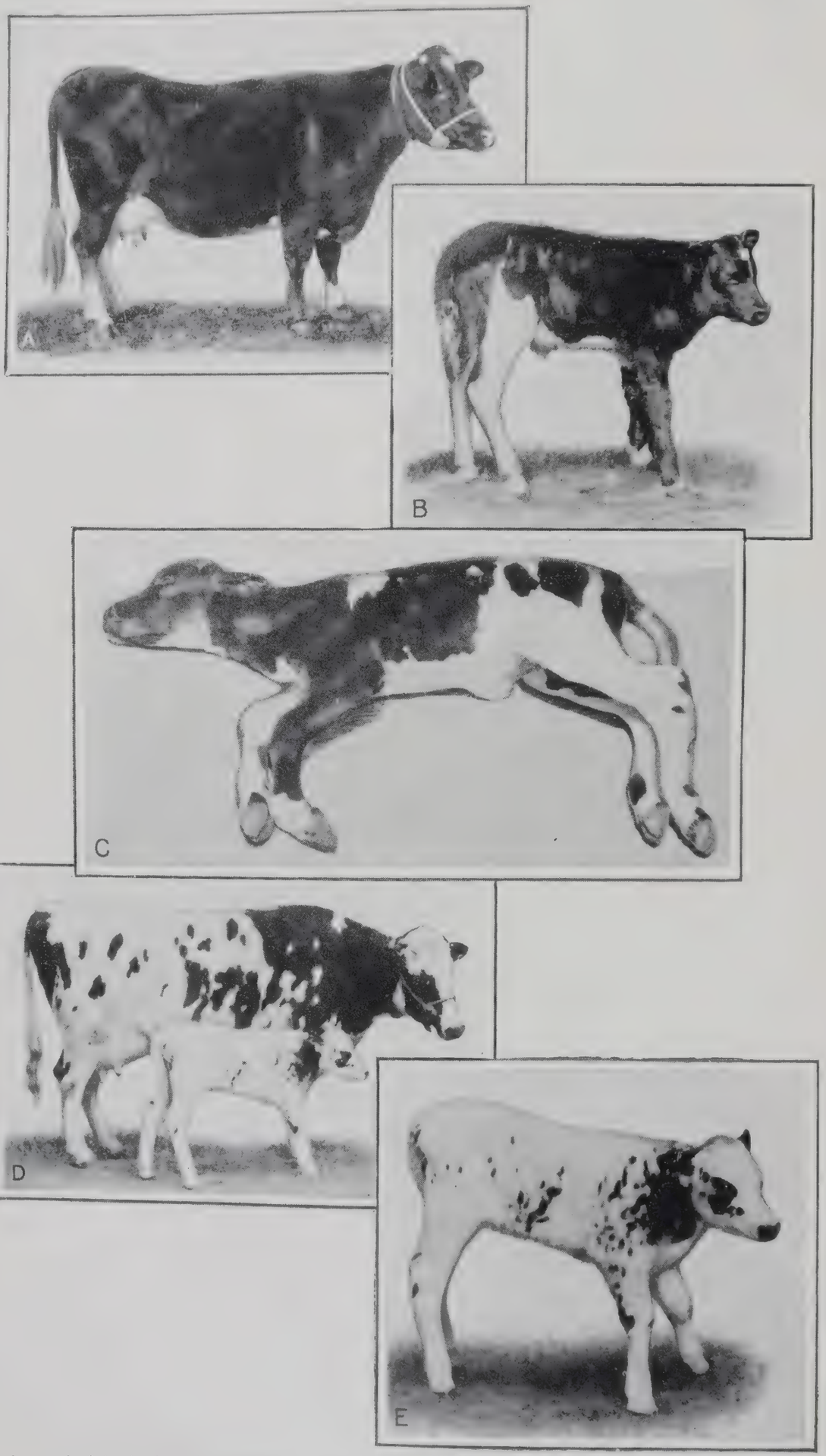
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PLATE 29

A–B.—A cow (No. 563) and her calf, showing the effect of a ration of corn grain, corn stover, sulphuric acid, and phosphoric acid. The ration was acid, and the urine produced was acid to litmus. The ammonia production in the urine was very high, yet the ration was physiologically perfect, and normal, strong offspring resulted. Note the good condition of both mother and calf.

C.—The calf of cow 642, showing the effect of a ration of wheat grain, wheat gluten, corn stover, and butter fat. A generous supply of fat-soluble A was not alone sufficient to make a ration rich in wheat grain always successful for reproduction. Such results as this make it clear that disaster with the wheat grain was not due to a deficiency but to a toxicity. The calf was born dead.

D–E.—A cow (No. 653) and her calf, showing the effect in 1915 of a ration of wheat grain, wheat gluten, corn stover, and butter fat. In this case successful reproduction resulted; but the fact that without the butter fat the ration was often successful illustrates the principle of individual resistance to the wheat toxicity, at least for a time. The calf was born strong. (See Pl. 24, *A–B*.)

PLATE 30

A–B.—The same cow (No. 653) shown in Plate 29, *D*, illustrating the effect in 1916 of the same ration as in 1915. This calf was born weak (fig. *B*). Note the deflection of the head and neck. It was unable to stand. Photographed a few hours after birth. Given the mother's milk it gradually improved, as shown in figure *A*. This illustrates how continuation of this ration over a second gestation period may weaken the offspring. The toxicity of the wheat grain was cumulative in effect.

C–D.—A cow (No. 562) and her calf, showing the effect of a ration of wheat embryo, corn starch, and corn stover. The embryo of the wheat grain carried a considerable mass of toxicity. Massing this in the ration brought on early abortion, with a gestation period of six to seven months. Note the very good general appearance of the mother.

E.—A cow (No. 654) and her calf, showing the effect of a ration of wheat grain, casein, and corn stover. This illustrates how by the improvement of the salt mixture of a ration and probably by introducing an abundance of the growth-promoting substances through the substitution of corn stover for wheat straw, and in addition by improving the proteins of the ration by the use of casein the wheat grain toxicity can be overcome. Both cow and calf were strong and vigorous.

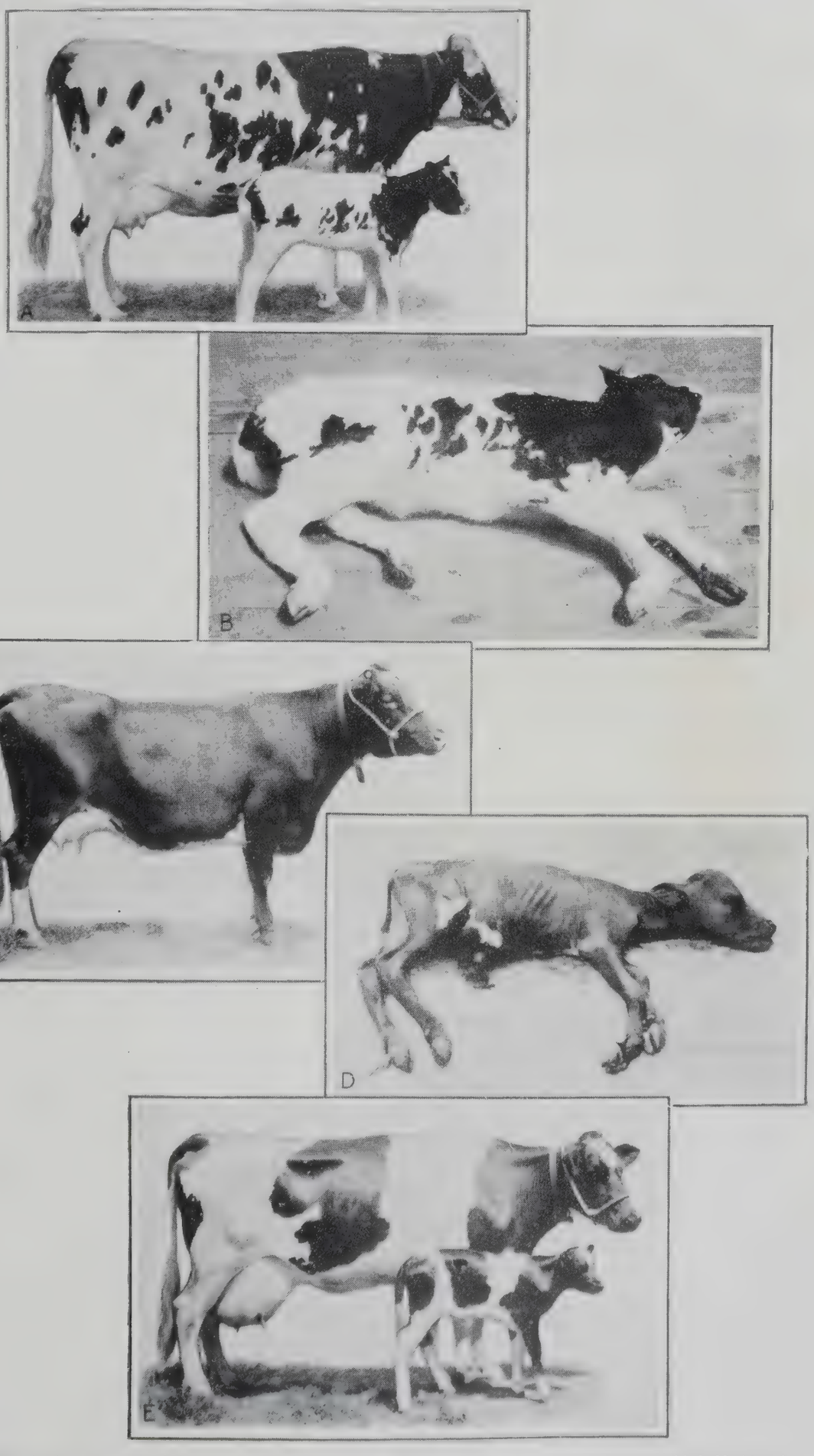
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PLATE 31

A–B.—Cow 642 and her calf, showing the effect of a ration of corn grain, wheat straw, and alfalfa hay. Without the alfalfa hay disaster in reproduction would have resulted. The calf was normal and vigorous.

C–D.—Cow 643 and her calf, showing the effect of a ration of corn grain, wheat straw, and alfafa hay. Without the alfalfa hay disaster in reproduction would have resulted. The calf was normal and vigorous.

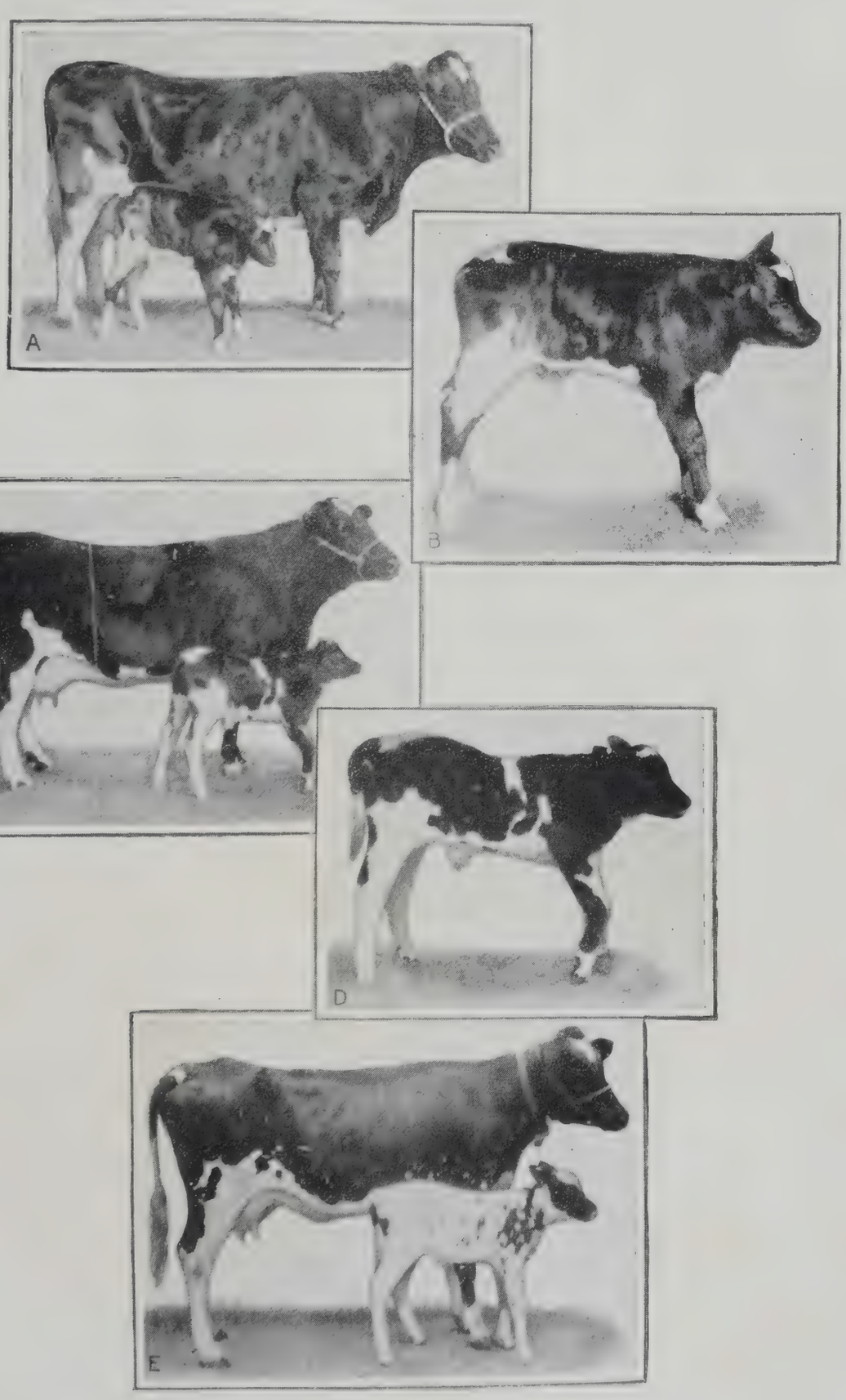
E–F.—The calf of cow 636, showing the effect of a ration of wheat grain, wheat straw, and alfalfa hay. The introduction of half of the roughage as alfalfa hay made the ration a success; at least for a single gestation period. The probable factors introduced were better ash, different proteins, and more of the growth-promoting substances fat-soluble A and water-soluble B. These factors enabled the animal to resist the effects of toxicity. The calf was strong.

PLATE 32

A–B.—A cow (No. 648) and her calf, showing the effect in 1915 of a ration of wheat grain, wheat straw, and alfalfa hay. With half of the roughage as alfalfa hay reproduction in the first gestation period was successful. The calf was normal and strong, and the cow was apparently healthy and vigorous.

C–D.—The same cow (No. 648), showing the effect in 1916 of the second gestation on the same ration, wheat grain, wheat straw, and alfalfa hay. This calf was carried to full time, but was weak and at first was fed from the bottle. It grew strong, but the fore legs were so weak that it stood for the first few days of its life on the first joints. This calf was blind. The mother remained in apparently good condition. This again illustrates the cumulative effect of wheat toxicity.

E.—A cow (No. 662) and her calf, showing the effect of a ration of corn meal, starch, wheat embryo, and corn stover. Successful reproduction in the presence of the embryo. At least for the first gestation the "antidotal" properties of corn meal and corn stover were sufficient to overcome the toxic effects of the wheat embryo. Without the corn meal and with only wheat embryo, starch, and corn stover in the ration reproduction would have been premature and the calf either dead or markedly undersized. (See Pl. 30, *D*.)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TOXIC VALUES AND KILLING EFFICIENCY OF THE ARSENATES

By A. L. LOVETT, *Entomologist*, and R. H. ROBINSON, *Assistant Chemist*,
Oregon Agricultural Experiment Station

INTRODUCTION

Investigations covering a period of years have been under way at the Oregon Agricultural Experiment Station to determine the killing efficiency of various poison sprays for insects. More recently the problem has resolved itself into a consideration of certain definite arsenical sprays, their relative values as insecticides, and a determination of the probable effective dilution for practical horticultural spraying.

The present paper deals with the results obtained in a study of the relative toxic value of pure samples of lead hydrogen arsenate (acid), basic lead arsenate (neutral), and calcium arsenate. A preliminary study of the relative toxicity of the arsenates of lead was made by Tartar and Wilson,[1] of this Station. The present report on the lead arsenates is the continuation of that work on an enlarged scale, which, in addition to affording further verification of their results, gives material data on the following points: (1) The comparative time required to kill small caterpillars and nearly mature caterpillars; (2) the approximate amount of lead hydrogen arsenate and basic lead arsenate required to kill small caterpillars and nearly mature caterpillars; (3) the proportion of these arsenates devoured by the small and mature caterpillars that passes through the alimentary canal of the larvæ.

In addition to similar comparative tests of the calcium arsenate, it was desired to determine the burning tendency on apple foliage (*Malus sylvestris*) in the field.

EXPERIMENTAL PROCEDURE

Our common tent caterpillar (*Malacosoma pluvialis* Stretch) was used throughout the whole series of experiments. The caterpillars were collected in the field almost wholly from the wild rose (*Rosa nukatana* Presl.). A few tents were obtained from the apple and some from *Crataegus* sp. In collecting the caterpillars the limb to which the tent was secured was severed and brought in, the caterpillars being disturbed as little as possible. All the larvæ used in one set or series of tests were collected

[1] TARTAR, H. V., and WILSON, H. F. THE TOXIC VALUES OF THE ARSENATES OF LEAD. *In* Jour. Econ. Ent., v. 8, no. 5, p. 481–486. 1915.

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July 23, 1917
Key No. Oreg.—1

the same day. The caterpillars varied considerably in size, particularly in the tests with the larger forms. Every reasonable effort was made to eliminate errors which might result from such variations in size or in the vitality. To accomplish this, the numerous tents and accompanying foliage were in some cases left piled together overnight. Most of the caterpillars would then collect on some prominent branch, and thus a very uniform mixing would be obtained; otherwise, care was taken to secure this uniformity when introducing the caterpillars to the sprayed foliage.

In all cases the solutions were applied to the foliage with an ordinary 1-quart glass-jar hand sprayer, care being taken to keep the material agitated and to get the solution thoroughly applied and evenly distributed. The solution was allowed to dry on the foliage before introducing the caterpillars. The specimens of sprayed foliage were transferred to vessels containing water, so that the foliage would remain fresh and attractive. Approximately 1,000 caterpillars were used in each test. From time to time a few would drop from the foliage and crawl away. These were always discarded.

Every day, Sundays excepted, following the introduction of the caterpillars, the dead larvæ (drop) were collected from the oilcloth spread under the vessels containing the foliage. The twig was first jarred sharply to dislodge any dead caterpillars that might be caught in the web. The caterpillars were picked up one at a time, carefully brushed with a camel's-hair brush, and placed in a paper sack, which was labeled with the test number, date, and total drop for the day. The excrement was then collected and run through a fine soil sieve to remove any bits of foreign material. Pieces of leaves, molted skins, etc., were carefully removed. The excrement was then placed in glass vials, properly labeled, and filed for analysis, after which the oilcloth was washed and dried.

The arsenates used in the experiments were prepared by one of us, in order that as pure a compound as possible could be assured. Lead hydrogen arsenate, basic lead arsenate, and calcium arsenate were employed. The lead arsenates were prepared as directed by Robinson and Tartar,[1] while the calcium arsenate, which is a salt of variable composition, was prepared by a method recently devised at this Station. It gave upon analysis the following composition:

	Per cent.
Calcium oxid (CaO), total	28.14
Arsenic pentoxid (As_2O_5), total	57.91
Water (H_2O), by difference	13.95

This approximates closely the theoretical composition of $CaH.AsO_4$.

[1] Robinson, R. H., and Tartar, H. V. The arsenates of lead. Ore. Agr. Exp. Sta. Bul. 128, 32 p., 3 fig. 1915.

EXPERIMENTAL WORK

SERIES A.—VERY SMALL CATERPILLARS

The caterpillars employed in series A were the very small ones and varied in size from those just hatched to forms about 5 to 7 days old (approximately 10 mm. in length). Both wild-rose and apple foliage was used. As the caterpillars were collected mostly on the rose, it was considered possible that for a time they might refuse to eat apple foliage and then feed to excess when they did begin. Since lead arsenate and water alone failed to stick well or spread evenly on the rose foliage, flour paste (1 pound of flour to 1 gallon of water) was prepared. This gallon of paste was diluted with 3 gallons of water and used at the rate of 20 c. c. to the 1,000 c. c. of lead-arsenate solution. No flour paste was added to the lead-arsenate solution on the apple foliage.

The strength of solutions used, date of application, and daily drop are recorded in Table I.

TABLE I.—*Effect of arsenates on very small caterpillars*

Kind and strength of solution.	Foliage.	Date sprayed.	Drop (April).														
			9	10	11	12	13	14	15	16	17	18	19	20	21	22	Total.
Lead hydrogen arsenate (acid) (2:50).	Rose..	Apr. 8	48	65	92	449	....	.....	....	....	....	....	....	....	....	.....	654
Do.....	Apple.	8	17	19	[a]752	.....	....	.....	....	....	....	....	....	....	....	.....	788
Basic lead arsenate (neutral) (2:50).	Rose..	8	39	155	181	141	720	.....	....	....	....	....	....	....	....	.....	1,236
Do.....	Apple.	8	5	22	163	83	522	.....	....	....	....	....	....	....	....	.....	795
Calcium arsenate (2:50).	Rose..	8	41	101	202	63	659	.....	....	....	....	....	....	....	....	.....	1,066
Do.....	Apple.	8	28	116	75	69	752	.....	....	....	....	....	....	....	....	.....	1,040
Lead hydrogen arsenate (acid) (1:50).	Rose..	8	49	84	160	1,264	....	.....	....	....	....	....	....	....	....	.....	1,557
Do.....	Apple.	8	27	54	88	859	....	.....	....	....	....	....	....	....	....	.....	1,028
Basic lead arsenate (neutral) (1:50).	Rose..	8	15	43	100	71	729	.....	....	....	....	....	....	....	....	.....	958
Do.....	Apple.	8	23	131	243	253	51	807	....	....	....	....	....	....	....	.....	1,508
Lead hydrogen arsenate (acid) (1:400).	Rose..	8	....	7	24	74	259	298	518	....	....	....	....	....	....	.....	1,180
Do.....	Apple.	8	....	7	62	236	424	1,151	....	....	....	....	....	....	....	.....	1,880
Basic lead arsenate (neutral) (1:400).	Rose..	8	....	4	6	23	39	63	36	....	[b]104	....	119	....	165	[a]342	901
Do.....	Apple.	8	....	4	3	1	15	4	0	....	[b]101	....	320	....	....	[a]1,035	1,483
Lead hydrogen arsenate (acid) (1:800).	Rose..	9	....	....	9	124	49	33	[b]59	....	111	121	[b]27	....	140	.....	673
Do.....	Apple.	9	....	....	16	45	0	195	[b]113	....	179	37	[b]13	....	312	.....	910
Lead hydrogen arsenate (acid) (1:1,200).	Rose..	9	....	....	21	93	247	313	[b]157	....	390	156	[b]47	....	....	[a]342	1,766
Do.....	Apple.	9	....	....	18	23	47	98	[b]54	....	126	44	[b]24	....	....	[a]310	744
Control.....	Rose..	8	....	....	....	.....	(b)	.....	....	....	(b)	....	....	(c)	....	.....	.....

[a] Very few; 15 to 20 yet on foliage show feeble signs of life.
[b] New foliage prepared and added.
[c] Discontinued.

SERIES B.—NEARLY MATURE CATERPILLARS

Series B was similar in every way to series A except that the caterpillars used were from half-grown to nearly mature larvæ and only apple foliage was used. The results are given in Table II.

TABLE II.—*Effect of arsenate on nearly mature larvæ*

Kind and strength of solution.	Date sprayed.	Drop (May).															
		5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	Total.
	May.																
Lead hydrogen arsenate (acid) (2:50).	4	40	39	....	264	286	....	.....	....	....	....	.....	.....	....	....	....	629
Basic lead arsenate (neutral) (2:50)...	4	....	....	....	121	287	....	46	....	....	....	.....	.....	....	....	....	454
Calcium arsenate (2:50).....	4	188	194	....	113	221	....	.....	....	....	....	.....	.....	....	....	....	716
Lead hydrogen arsenate (acid) (1:50).	4	38	373	....	392	217	....	.....	....	....	....	.....	.....	....	....	....	1,020
Basic lead arsenate (neutral) (1:50)...	4	....	....	....	87	234	125	43	....	....	....	.....	.....	....	....	....	489
Calcium arsenate (1:50).....	4	136	371	....	334	241	....	.....	....	....	....	.....	.....	....	....	....	1,082
Lead hydrogen arsenate (acid) (1:100).	5	....	82	....	483	331	....	98	....	....	....	.....	.....	....	....	....	994
Lead hydrogen arsenate (acid) (1:400).	5	....	6	....	22	163	162	[a]151	426	107	136	.....	.....	....	....	....	1,173
Calcium arsenate (1:400).....	4	....	73	....	481	397	116	124	....	....	....	.....	.....	....	....	....	1,191
Lead hydrogen arsenate (acid) (1:800).	5	....	12	....	34	123	164	[a]203	279	108	....	.....	201	....	....	....	1,112
Calcium arsenate (1:800).....	4	....	10	....	152	370	191	117	....	....	....	.....	.....	....	....	....	850
Lead hydrogen arsenate (acid) (1:1,200).....	5	....	7	....	2	16	23	[a]33	145	187	....	153	[a]103	....	318	39	1,026
Control.....	6	....	....	....	....	....	(a)	.....	....	....	....	(a)	.....	....	(b)	....	.....

[a] New foliage prepared and added. [b] Two parasitized.

DISCUSSION OF RESULTS

The results of the tests to determine the relative killing efficiency of the hydrogen and basic lead arsenate as shown by data contained in the above tables (I and II) and summarized in Table IV approximate very closely those obtained by Tartar and Wilson[1] in 1915 and substantiate in general the work of previous investigators, in that the acid arsenate has a decidedly higher killing efficiency at a given dilution than does the neutral arsenate. It will be noted that the figures in the tables do not emphasize the differences in killing efficiency of these arsenates, particularly with the more concentrated solutions, but observation during the actual tests showed the differences clearly. Had the drop been recorded more frequently than every 24 hours, this difference, as indicated in the tables, would probably have been more marked. From Tables II and IV it is seen that until the fourth day no caterpillars died on the twigs sprayed with neutral lead arsenate, while both the acid lead

[1] TARTAR, H. V., and WILSON, H. F. Op. cit.

arsenate and calcium arsenate were very effective toxic agents on the first day. In regard to rapidity of action and killing efficiency, calcium arsenate and acid lead arsenate were approximately the same.

A comparison of the relative time required to kill the small larvæ and the nearly mature caterpillars, as indicated in Table IV, shows that although there was a higher percentage of the latter dropped in the early days of the test, it required a longer period to kill all of the larger forms.

CHEMICAL ANALYSIS

After the collection and drying of the poisoned caterpillars and excrement from the various tests, the arsenic content was determined. The method used is as follows: A counted number of caterpillars, or excrement therefrom, were accurately weighed and introduced into a Kjeldahl flask (500 c.c. capacity) together with about 15 c.c. of arsenic-free concentrated sulphuric acid. The flask was then placed over a free flame and arsenic-free nitric acid added in small quantities at short intervals until all of the organic matter was oxidized and the solution was perfectly clear. The solution was allowed to digest over a hot flame for an hour, when all the nitric acid was expelled and white fumes of sulphuric acid (H_2SO_4) were given off. Following the digestion, the excess of sulphuric acid was driven off and the arsenic determined by titration with *N/100* iodin solution after reduction with potassium iodid according to the modified Gooch and Browning [1] method.

For convenience in making comparisons, the results of the chemical analysis are calculated in milligrams contained in the amount of sample taken and also the equivalent amount in 1 gm. of dried sample. Table III gives the data obtained.

These results throughout show consistently a higher arsenic content in the tissue and a lower arsenic content in the corresponding excrement with lead hydrogen arsenate as the spray than with either the basic lead arsenate or calcium arsenate. Calcium arsenate comes second in this comparison, while the basic lead arsenate contained the smallest amount of arsenic in the tissue and shows that a large amount passed through the intestinal tract unchanged, most of the arsenic eaten being found in the excrement.

A further study of the ratio of arsenic in the tissue to that contained in the excrement brings out some very interesting facts. In Tables III and IV we note for lead hydrogen arsenate (2:50) that there was found 0.90 mgm. of arsenic pentoxid per gram of tissue, as compared with 0.49 mgm. of arsenic pentoxid per gram of excrement, or a ratio of 1 to 0.544; in the calcium arsenate (2:50) there was 0.83 mgm. per gram of tissue

[1] WILEY, H. W., ed. OFFICIAL AND PROVISIONAL METHODS OF ANALYSIS, ASSOCIATION OF OFFICIAL AGRICULTURAL CHEMISTS, AS COMPILED BY THE COMMITTEE ON REVISION OF METHODS. U. S. Dept. Agr. Bur. Chem. Bul. 107 (rev.), p. 239. 1908. Reprinted in 1912.

and 0.64 mgm. in the excrement, or a ratio of 1 to 0.70; in the basic lead arsenate (2:50) there was 0.35 mgm. per gram of tissue and 0.53 mgm. in the excrement, or a ratio of 1 to 1.51. This ratio varies somewhat in the weaker strengths, but is consistent throughout, in that the amounts of arsenic are higher in the tissue and lower in the excrement in the relative order as noted above.

TABLE III.—*Arsenic consumed by caterpillars*

Kind and strength of solution.	Number of caterpillars.	Dry caterpillars.			Dry excrement.		
		Weight.	Arsenic pentoxid.		Weight.	Arsenic pentoxid.	
			Total.	Per gram of tissue.		Total.	Per gram of excrement.
VERY SMALL CATERPILLARS							
		Gm.	*Mgm.*	*Mgm.*	*Gm.*	*Mgm.*	*Mgm.*
Lead hydrogen arsenate (acid) (2:50)	1,442	0.3130	0.23	0.74	0.0200	0.058	0.28
Lead hydrogen arsenate (acid) (1:400)	3,060	1.0625	.17	.19	.3700	.086	.23
Lead hydrogen arsenate (acid) (1:800)	1,583	.7200	.12	.18	.3400	.086	.25
Lead hydrogen arsenate (acid) (1:1,200)	2,510	.9870	.14	.15	.4500	.12	.25
Basic lead arsenate (neutral) (2:50)	2,031	.5500	.17	.31	.0900	.065	.72
Basic lead arsenate (neutral) (1:50)	2,466	.5920	.23	.39	.0650	.058	.89
Basic lead arsenate (neutral) (1:400)	2,384	1.6520	.29	.17	1.3400	.17	.13
Calcium arsenate (2:50)	2,106	.5800	.23	.40	.....	.....	.....
NEARLY MATURE CATERPILLARS							
Lead hydrogen arsenate (acid) (2:50)	383	5.7350	5.10	0.90	0.4700	0.23	0.49
Lead hydrogen arsenate (acid) (1:50)	803	4.3025	2.19	.51	.6300	.23	.36
Lead hydrogen arsenate (acid) (1:100)	565	4.7832	1.73	.36	1.1200	.12	.11
Lead hydrogen arsenate (acid) (1:400)	586	5.0720	.64	.13	2.0100	.17	.09
Lead hydrogen arsenate (acid) (1:800)	556	5.0540	.63	.12	2.8150	.23	.08
Lead hydrogen arsenate (acid) (1:1,200)	513	4.2080	.63	.16	2.8840	.23	.08
Basic lead arsenate (neutral) (2:50)	287	3.2800	1.15	.35	1.4030	.75	.53
Basic lead arsenate (neutral) (1:50)	455	3.7950	1.04	.28	1.6300	.58	.35
Calcium arsenate (2:50)	185	3.8950	3.22	.83	.5400	.34	.64
Calcium arsenate (1:50)	705	5.8760	1.90	.32	1.0480	.46	.44
Calcium arsenate (1:400)	532	4.6900	.63	.14	2.2700	.35	.15
Calcium arsenate (1:800)	152	1.4200	.17	.12	3.9783	.40	.11

This may be explained as being due to the relative stability of the three salts, since lead hydrogen arsenate and calcium arsenate are comparatively unstable compounds and would probably react more readily with the body juices, permitting a large amount of the arsenic to be assimilated and therefore retained within the tissue. The basic lead arsenate, on the other hand, is a very stable salt and would probably pass through the body comparatively unchanged, so that more arsenic would be found in the excrement than in the tissue.

TABLE IV.—*Comparative results of tests to determine the relative killing efficiency of arsenates*

Kind and strength of solution.	Number of days after being introduced that first caterpillars died.		Percentage of caterpillars dead first day of drop.		Total number of days to kill.		Approximate amount of total arsenic devoured per 1,000 caterpillars.		Ratio of arsenic pentoxid in tissue is to arsenic pentoxid in excrement.	
	Small caterpillars.	Mature caterpillars.	Small caterpillars.	Mature caterpillars.	Small caterpillars.	Mature caterpillars.	Small caterpillars.	Mature caterpillars.	Small caterpillars.	Mature caterpillars.
							Mgm.	*Mgm.*		
Lead hydrogen arsenate (2:50)	0	0	4.5	6.36	4	5	.....	11.815	.....	1:0.5440
Lead hydrogen arsenate (1:50)	0	0	2.94	2.74	4	5	.....	7.395	.....	1: .7058
Lead hydrogen arsenate (1:100)	.....	0	.....	8.25	.....	6	.....	3.995	.....	1: .3055
Lead hydrogen arsenate (1:400)	1	0	.46	.50	7	9	.1595	1.870	1:1.2100	1: .6900
Lead hydrogen arsenic (1:800)	1	0	1.58	1.08	12	8	.1633	1.700	1:1.3888	1: .6660
Lead hydrogen arsenate (1:1,200)	1	0	1.55	.68	13	14	.1519	2.040	1:1.6660	1: .5000
Basic lead arsenate (1:50)	0	3	2.17	26.65	5	7	.3911	.486	1:2.3230	1:1.5100
Basic lead arsenate (1:50)	0	3	1.52	18.00	6	7	.4860	5.355	1:1.7650	1:1.2500
Basic lead arsenate (1:400)	1	.....	.34	.....	14	.....	.1139	.....	.....	.....
Calcium arsenate (2:50)	0	0	3.28	26.53	5	5	(a)	.....	.....	.....
Calcium arsenate (1:50)	.....	0	.....	12.56	.....	5	.....	.....	.....	.....
Calcium arsenate (1:400)	.....	1	.....	6.13	.....	5	.....	.....	.....	.....
Calcium arsenate (1:800)	.....	1	.....	1.17	.....	7	.....	.....	.....	.....

[a] Excrement not analyzed.

These results indicate that the lead hydrogen arsenate is the best spray for rapid effective killing, since a larger quantity of the poisonous element is assimilated by the caterpillar than either of the other types. Assuming that the lead hydrogen arsenate approximates closely an efficient insecticidal spray and calculating from the figure obtained as given in the above tables at the dilution 1 to 400, we may generalize as follows relative to the specific amount of arsenic pentoxid necessary to kill a certain number of caterpillars: It required approximately 0.1595 mgm. of arsenic pentoxid to kill 1,000 of the small tent caterpillars and 1.87 mgm. to kill a like number of the nearly mature larvæ. It is also interesting to note that, although a large percentage of the basic lead arsenate passes through the intestinal tract, the total amount of arsenic pentoxid devoured is about the same as for lead hydrogen arsenate—namely, 0.1139 mgm. for 1,000 caterpillars. It is supposed from the data, therefore, that it takes approximately the same quantity of arsenic, whether from lead hydrogen or basic arsenate, to kill equal numbers of caterpillars, but the amount varies greatly, depending upon the size of caterpillars used.

FIELD EXPERIMENTS WITH CALCIUM ARSENATE

Since but limited work has been done on the effects of calcium arsenate as a spray under climatic conditions existing in the Pacific Northwest, a preliminary field test was made in connection with the preceding

series of experiments to ascertain the burning tendencies of calcium arsenate upon foliage.

Two types of calcium arsenate were used: the calcium arsenate ($CaH.AsO_4$) described above and calcium ammonium arsenate, obtained by treating the former calcium arsenate with 2 per cent ammonium hydroxid, washing the resulting salt free of ammonia and drying at 110° C.

The analysis of the salt thus obtained is as follows:

	Per cent.
Calcium oxid (CaO), total	37.03
Arsenic pentoxid (As_2O_5), total	52.02

These two spray materials were tested out upon the foliage of young apple trees in the Oregon Experiment Station orchard. The trees were thoroughly and uniformly covered with the spray solutions. The suspension qualities of both materials were very poor, and they appeared on the foliage as coarse granules.

The different strengths of the spray as used were as follows:

No. 1. Calcium hydrogen arsenate (2:50), or 4.8 gm. in 1,000 c. c. of water.
No. 2. Calcium hydrogen arsenate (1:50), or 2.4 gm. in 1,000 c. c. of water.
No. 3. Calcium hydrogen arsenate (1:100), or 1.2 gm. in 1,000 c. c. of water.
No. 4. Calcium ammonium arsenate (2:50), or 4.8 gm. in 1,000 c. c. of water.
No. 5. Calcium ammonium arsenate (1:100), or 1.2 gm. in 1,000 c. c. of water.

The application was made on June 22, 1916. Showers were frequent the following two days, but, on examination of the foliage, material as coarse and granular as when applied was still evident. There was no indication of burn at this time. Frequent showers continued, and on June 28 the following effect was noted:

No. 1. Burn on leaves general, though scattered; spots of fair size.
No. 2. Burn on leaves general, though scattered; spots small.
No. 3. Burn slight, scattered; spots small.
No. 4. About same as No. 2.
No. 5. Burn about as general as No. 4; spots very small.

From this date on the burn spread slowly but steadily, and occasional showers continued. An examination on July 2 showed the burn to be spreading and in all cases was too severe for practical use.

From these preliminary tests and under the climatic conditions noted, calcium arsenates can not, at present, be recommended as a safe spray material.

SUMMARY

(1) Lead hydrogen arsenate has a higher killing efficiency at a given dilution than either calcium or basic lead arsenate.

(2) It requires a longer period of time to kill the nearly mature caterpillars than the small forms.

(3) All of the arsenic devoured by the insects in feeding upon sprayed foliage is not assimilated, but a portion passes through the intestinal tract in the excrement. The percentage amount of the arsenic assimilated depends upon the arsenate used; lead hydrogen arsenate was assimilated readily and most of the arsenic was retained in the tissue, while much of the basic lead arsenate was found in the excrement.

(4) It requires approximately 0.1595 mgm. of arsenic pentoxid to kill 1,000 small tent caterpillars, and approximately 1.84 mgm. of arsenic pentoxid to kill 1,000 nearly mature tent caterpillars, irrespective of the particular arsenate used as a spray.

(5) Preliminary experiments on the burning effects of calcium arsenate indicate too severe injury to warrant the practical use of this spray.

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EVAPORATION FROM THE SURFACES OF WATER AND RIVER-BED MATERIALS

By R. B. SLEIGHT,

Assistant Irrigation Engineer, Office of Public Roads and Rural Engineering, United States Department of Agriculture

INTRODUCTION

The Irrigation Field Laboratory at Denver, Colo., where the following experiments were made, was established for the purpose of studying from an engineering standpoint problems connected with the utilization of water in irrigation. It is a laboratory of such size and kind that natural phenomena may be observed under conditions somewhat less artificial than are usual in laboratory work. An examination of figure 1 will show the general exposure and topography of the laboratory tract. This field (22),[1] though it has the conveniences and facilities of a city location, is as open to the elements as the prairie homestead.

A maximum elevation of 5,346.4 feet above sea level is reached at one point of the tract. The surrounding country, except to the east, is lower. The grade to the east is very slight and the country is open prairie. All buildings in the immediate section of Denver are shown; these are generally of the one-story or bungalow type, and offer no interference with experiments that may be in progress, since the nearest is some 200 feet from the laboratory. Figure 2, which shows the layout of the laboratory for the season of 1916, indicates the location of such facilities as electric power, water supply, etc. The hillside provides a 20 per cent slope for the flow of water and furrow work. The panorama (Pl. 33) supplements the information given by figures 1 and 2. Surrounded by a 6-foot 3-inch mesh woven wire fence, with top and bottom barbed wires, the field has been free from animals. A rule that has been rigidly enforced is that visitors are not permitted except when accompanied by some member of the organization.

At the beginning plans were started for a study of duty of water and movement of water through soils. Evaporation has a large part in the apparent efficiency of the use of irrigation water. Evaporation measurements and data available were not considered sufficient for the requirements of the proposed work. It was therefore necessary at first to carry

Reference is made by number to "Literature cited," p. 259–261.

on quite an extensive evaporation investigation. Available funds limited the work of 1916 to this evaporation study, divided into two important parts—that from water surfaces and that from the surfaces of river-bed materials.

PART I.—EVAPORATION FROM WATER SURFACES

An early study of evaporation was that of Perrault, who worked with water and soils in 1670 (20). Dalton in 1802 (6) first put his investigations into definite form, and Dalton's law has been used by more recent experimenters as a basis for the expressions which they have proposed for calculating evaporation rates. A bibliography of some length prepared in 1908 (19) would tend to show that evaporation research is not in a pioneer state. Noteworthy among the investigations are these: Thirteen years' work at Lee Bridge, London, England (12); 11 years' records at Boston, Mass. (9); records at Rochester, N. Y., from 1891 to the present (21); records at Fort Collins, Colo., from 1887 to the present (5, 25); several investigations of the Army engineers (15); measurements made at Salton Sea (2); at Owens Valley (18); Coyote (7); and Kingsburg, Cal. (4); and miscellaneous studies by the United States Weather Bureau, the United States Reclamation Service, the United States Geological Survey, and the Division of Irrigation Investigations of this Office. However, a recent paper (8) describing the problem of arriving at the amount of evaporation from a reservoir brought out such discussion as to indicate that there is much uncertainty concerning the interpretation of the available data. Regarding the rates of evaporation from water surfaces of varying sizes, one investigator (3, p. 1134) says regarding the coefficients proposed:

> These should be further verified if possible.

Other important points were not definitely determined, and fundamental engineering data upon which to base irrigation research were not available. Accordingly arrangements were made to make studies along the following lines:

(*a*) Variation in the amount of evaporation from pans of varying sizes.

(*b*) Variation in the amount of evaporation from pans of varying depths.

(*c*) A comparison of the amount of evaporation from flowing and still water.

(*d*) A comparison of the results obtained from different types of so-called standard evaporation pans.

(*e*) A comparison of the evaporation amounts from round pans and square pans of small size.

(*f*) An extension of the results of experimental pans to larger water surfaces.

The results of these studies are presented, not as formulas which may be misinterpreted and used where there is no justification for their use, but as curves based upon the original data which clearly show the limits

FIG. 1.—Map showing the general exposure and topography of the section of South Denver, Colo., adjacent to the Irrigation Field Laboratory of the Office of Public Roads and Rural Engineering.

of application of these data, or as coefficients from these curves. It is the aim to make this investigation of practical value to the hydraulic engineer, in direct contradiction to the statement below, which shows the

attitude which has characterized some of the past evaporation investigations.

Of course, hydraulic and irrigation engineers need to know the loss of water by evaporation, but in nature this is so mixed up with seepage, leakage, and consumption by animals and plants that our meteorological data are of comparatively little importance. (1, p. 255.)

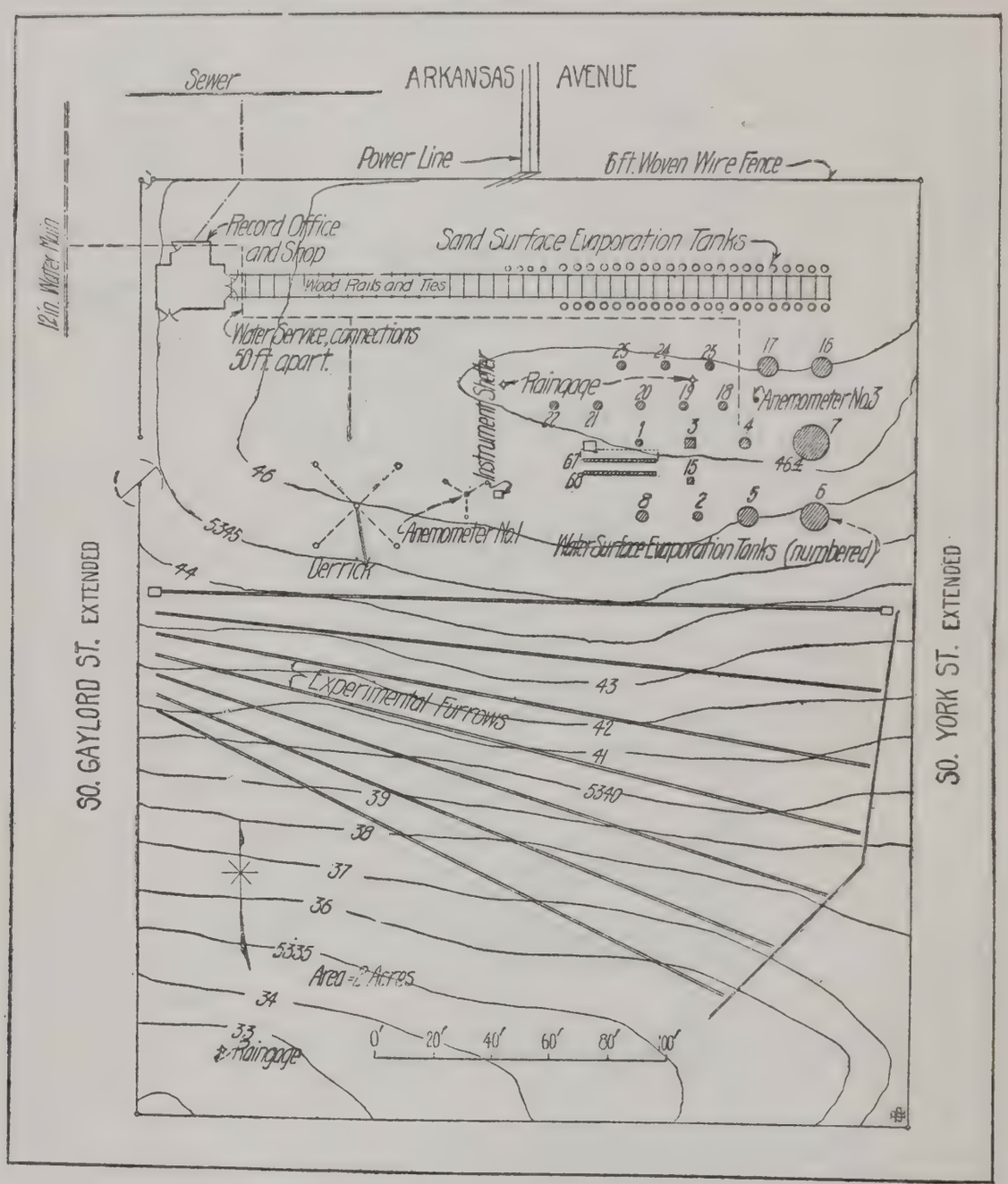

FIG. 2.—Map showing layout of Irrigation Field Laboratory for season of 1916.

EQUIPMENT

The apparatus necessary for the work, including all evaporation pans, all measuring devices for evaporation, and all meteorological instruments, were specially installed for the investigation. All evaporation pans and tanks were numbered in the order of their installation. Since the numbering also groups tanks of similar style, it has been followed throughout

this discussion. The number is given, together with the description, in Table I. All tanks are galvanized metal. The location of each is shown in figure 2.

TABLE I.—*Description of pans used in evaporation studies*

Tank No.	Exposed area.	Depth.	Water depth.	Set in ground.	Remarks.
		Feet.	*Feet.*	*Feet.*	
1	1 foot diameter.....	3	2.75	2.75	Similar to figure 3, *B*.
2	2 feet diameter.....	3	2.75	2.75	Do.
3	3 feet square.....	3	2.75	2.75	Similar to figure 3, *B;* shown in Plates 34, *B*, and 36, *B*.
4	3.39 feet diameter...	3	2.75	2.75	Similar to figure 3, *B;* shown in Plate 34, *C*. Hoff evaporimeter is attached to this tank.
5	6 feet diameter.....	3	2.75	2.75	Similar to figure 3, *B*.
6	9 feet diameter.....	3	2.75	2.75	Do.
7	12 feet diameter.....	3	2.75	2.75	Similar to figure 3, *B*, and shown in Plates 34, *C*, and 35, *B*.
8	4 feet diameter.....	.83	.62	Above.	Similar to figure 3, *A*. United States Weather Bureau standard for class A station. Shown in Plate 37, *A*.
9	3 feet square.....	1.5	1.25	.....	Similar to figure 3, *C*. United States Geological Survey standard floating pan. See Plate 37, *B*.
14	.....	.....	.....	.....	Piche evaporimeter in instrument shelter.
15	1.77 feet square.....	3	2.75	2.75	Similar to figure 3, *B;* shown in Plate 36, *B*.
16	6 feet diameter.....	2	1.75	1.75	Similar to figure 3, *B*.
17	.....do.....	1	.75	.75	Do.
18	2 feet diameter.....	6	5.75	5.75	Do.
19	.....do.....	2	1.75	1.75	Do.
20	.....do.....	1.5	1.25	1.25	Do.
21	.....do.....	1	.75	.75	Do.
22	.....do.....	.50	.25	.25	Do.
23	.....do.....	1	.75	.75	Similar to figure 3, *B;* shown in Plate 36, *B*. Heated by electric lamp.
24	.....do.....	1	.75	.75	Do.
25	.....do.....	1	.75	.75	Do.
26	1.77 feet square.....	3	2.75	2.75	Similar to figure 3, *B*, but arranged for water circulation.
67	1 by 25 feet.....	.50	.25	.25	Shown in Plate 36, *A*. Arranged for flowing water.
68	.....	.....	.....	.....	Similar to tank 67, but water does not flow.

Throughout the work actual measurements of evaporation were made by hook gage, observations being to the water surface with the hook gauge set at the definite and fixed datum on the rim of the tank. The type of gage used is that developed by E. J. Hoff, of this Office, for evaporation work (24) and is shown in Plate 34, *A*. But two gages were used throughout the progress of all the measurements, one of them kept for use with tank 9 (floating) and the other for use at the labora-

tory proper. A Hoff recording gage (16) was installed in connection with tank 4, making it possible to keep a continuous record of the lowering of the water surface of that tank. The Weather Bureau type of

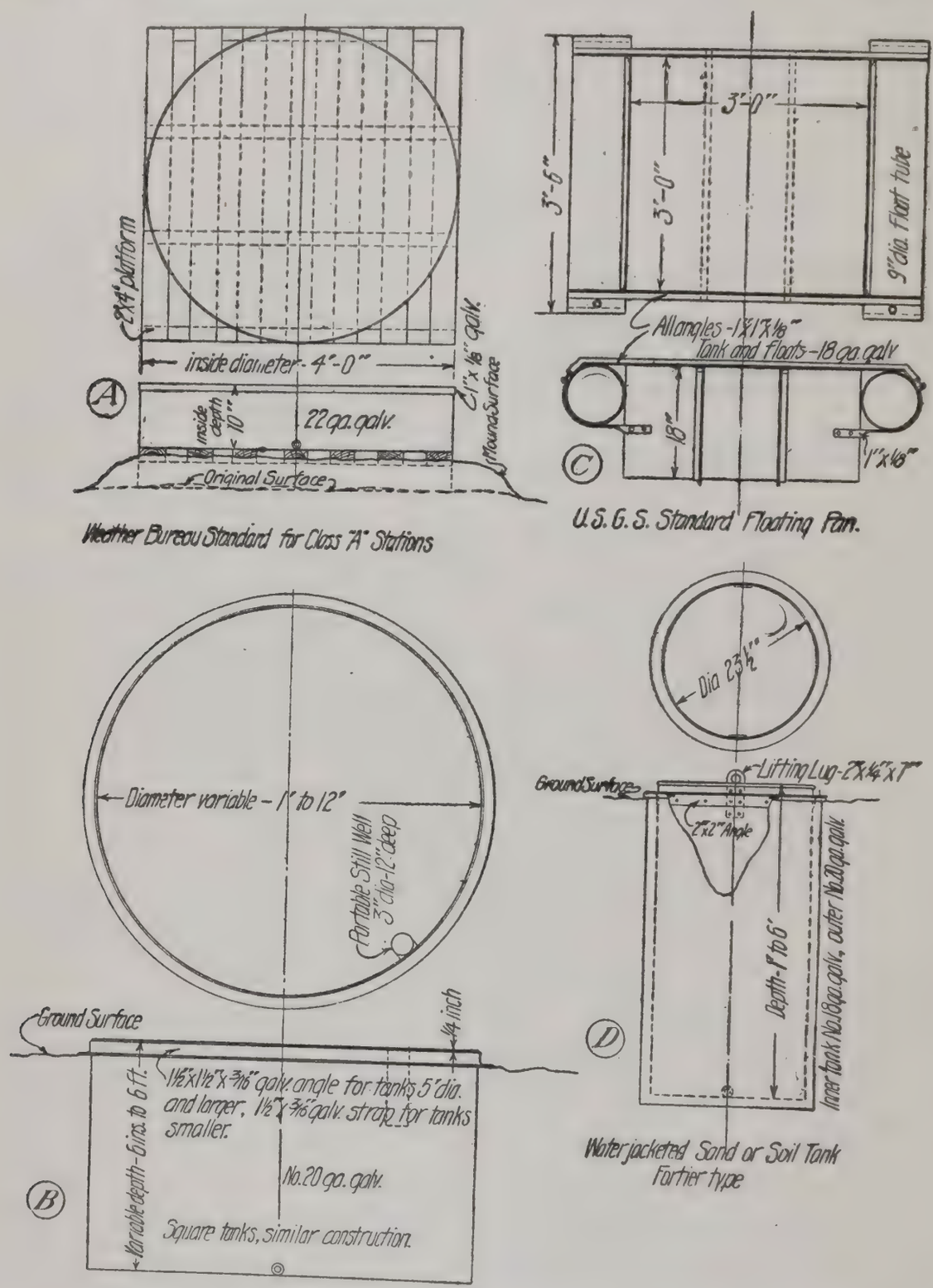

FIG. 3.—Sketch showing types of evaporation tanks in use at the Irrigation Field Laboratory.

still well (17) was used in tank 8, but with the Hoff gage. During the early spring months a special portable still well (fig. 3, *B*) was used when observations were taken at the other tanks. Later in the season

its use was discontinued, wind conditions being such that it was no longer necessary.

Instruments were installed for making quite complete meteorological records to accompany the evaporation figures. All apparatus were of the standard type in use by the Weather Bureau and were accurately calibrated. The location of the instrument shelter is shown in figure 2 and Plate 33. In addition to the maximum and minimum thermometer equipment, it housed the Piche evaporimeter, thermograph, and hygrograph. Both sling and whirling psychrometers were used. Three anemometers were in use, two being shown in figure 2—No. 1 on a 14-foot tower and No. 3 with cups about 2 feet above the ground to conform with Weather Bureau specifications for class A evaporation stations. The anemometer register attached to No. 3 is in the record office. No. 2 was located on the Washington Park Lake near by. The cups of this instrument were about 2 feet above the water (Pl. 37, *B*). A test run of the three instruments is shown in Plate 35, *A*. Four rain gages were in use during the season—three at the laboratory, as shown on the sketch, and one at the lake.

Water temperature records were obtained by the use of maximum and minimum thermometers with the bulb immersed to the depth 0.05 foot in the tanks. The arrangement shown in tank 3 (Pl. 34, *B*) was first used. Later, the thermometers were floated in the water, held up by means of a test tube 1 by 8 inches. This means allowed a control of the depth of the bulb without adjustment after the installation and further placed all metal under the surface. Careful comparisons showed that the effect of this glass tube is not measurable, either in amount of evaporation by a hook gage reading to 0.001 foot or in water temperature by thermometers reading to 1°, on a tank 2 feet in diameter. The thermometer tube without the metal mounting was tried, but the breakage in wind made a continuance inadvisable. Floating maximum and minimum thermometers in tank 8 are shown in Plate 37, *A*. A thermograph for water was attached to record continuously the temperature of the water at the surface of No. 4.

The barometer and barograph were located in the record office.

OBSERVATIONS

Tanks 1 to 8 were installed and were ready for use on November 1, 1915. Observations were begun at that time, records of evaporation being kept, and full readings from all meteorological instruments were taken. Other tanks were added from time to time until the end of the season 1916. The dates of the increase of equipment are indicated by the dates in the various tables presenting detailed results of the work.

Throughout care has been taken to make all observations in accordance with the rules of the United States Weather Bureau; and, in case

there are differences in methods, that recommended for evaporation (17) work has been followed. For example, the Denver branch of the Weather Bureau makes observations regularly at 6 o'clock mountain time. Weather Bureau regulations for evaporation observations recommend 7 o'clock, which hour has been used as far as possible, both morning and night. Readings were taken once a day from the beginning of the work until April 1, 1916. From then until October 5, 1916, observations were made twice a day, and then for the remaining portion of the year discussed herein regular readings at 7 a. m. only. Special and check readings were taken at various times of the day and night.

ACCURACY OF MEASUREMENTS

No observer worked for a shorter time than one month, during which period he was responsible for all the readings from a particular set of instruments or tanks. He made from 60 to several hundred observations. Thus, the error resulting from frequent change of men, that of personal equation, has been eliminated as far as possible.

The hook gage used for determining water losses by evaporation is calibrated to 0.001 foot. Neither the gage used at the lake nor the one at the laboratory was changed throughout the season. The datum on each tank remained unchanged also. Some difficulty was expected and found when measurements were made during winds. The still well was of great benefit on the smaller pans, but on the large tanks a high-velocity wind piles the water up at one side, so that a hook-gage reading might not necessarily indicate the true water level for the pan as a whole. Check observations were always made after a windstorm, and, even though individual figures were in error, the weekly totals, which have been used in the computations, have eliminated largely the errors due to wind movement. Plate 34, *B*, shows another result of a windstorm. The blown sand is caked at the side of the tank. The amount that actually is blown into the tank is difficult to estimate, but is small for the year. The catching of sand can not be prevented when the tank is exposed where sandstorms occur. Attention is called to Plate 34, *C*, which shows a typical winter condition. Regular observations of evaporation were not attempted for the time during which the ice surface was not readily broken. This period is indicated on the table of results. The figures are more consistent than was expected, since the addition by snow to an evaporation tank, having the surface of the water at about the same level as the ground surface at that point, can not be accurately determined from rain-gage results. Water in the tank may be slightly warmer than freezing at the beginning of the snowstorm, and all the snow may be retained by the tank. It then becomes colder and freezes; part of the snow may then drift up against the rim of the tank and part be

blown away, or, without wind, it may cover the ice evenly. The larger tank shown in Plate 34, *C*, has but little snow on the ice; the smaller has considerable, frozen around the rim. Measurements from tanks of this type where the water is frozen for a part of the year, while of some value, do not necessarily show the true evaporation.

Anemometer readings were taken to 0.1 mile, and in the test shown in Plate 35, *A*, the two anemometers at the ends checked within 0.2 mile for 24 hours. A correction scale for the instrument in the center was prepared from a two weeks' run, and an accuracy of about 0.4 mile in 24 hours was obtained in comparison with the two others.

All thermometers used are calibrated to 1 degree; readings were taken to the nearest half-degree. Each of the thermometers in use had been compared with a standard thermometer, and in no case has a difference in scale readings of more than 0.25° been found. Only the highest grade instruments of recognized standard makes have been purchased.

DETAIL WORK OF OBSERVATIONS

The forms made up for work at the Denver laboratory show the readings taken at each regular observation. In addition to these, there were many additional records and check readings made.

Two special forms are used. The first has the following columns: "Date;" "Time;" general heading "Barometer," under which come "Attached thermometer," "Observed barometer," "Correction," "Corrected barometer;" general heading "Thermometer," under which are "Set maximum," "Minimum," "Maximum," "Wet," "Dry," "Dew point," "Relative humidity;" the general heading "Precipitation," covering "Beginning," "Ending," "Rain gage No. 1 (inches)," "Rain gage No. 2 (inches)," "Snowfall (inches);" and the heading "Wind," which is subdivided into "Direction at time," "Anemometer No. 1, movement since last reading," "Anemometer No. 2, movement since last reading," "Hours since last reading;" and several columns for remarks or additional readings. The second form is used for evaporation alone and has the columns headed: "Date;" "Time;" "Hours since last observation;" general heading "Evaporation Tank No.," which covers the observations on that particular tank; "Hook gage, evaporated since last observation," a blank column for filling notes, maximum thermometer, minimum thermometer. Space for five evaporation tanks and remarks is available on one form.

New record sheets are required each week on the thermograph for air, thermograph for water, hydrograph and barograph. These changes are made Monday forenoon. Twenty-four hours are covered by each sheet of the anemometer register, and the requirement of new sheets for the evaporimeter depends upon the rate of evaporation.

EVAPORATION FROM CIRCULAR LAND TANKS OF DIFFERENT DIAMETERS.

This study, the first one begun at the laboratory, was started in November, 1915, and the results of one year's work are given. Tanks 1, 2, 4 (Pl. 34, *C*), 5, 6, and 7 (Pl. 34; *C*, 35 *B*), described previously, are of a type used by the Office of Public Roads and Rural Engineering and at several State Experiment Stations throughout the country. This general style of tank most nearly approximates the reservoir, and the results obtained can be more safely extended to the reservoir of some size. While of metal, but a small rim of this metal is above the ground surface; hence, but little heat derived from the sun's rays is conducted to the water. Further, since the tank is largely below the ground surface, radiation from the tank takes place from the water surface only. The same conditions are true of the reservoir. The more "unnatural" evaporation pan, that setting wholly above the ground and usually made of metal, is subjected in the greatest possible extent to the concentration and radiation effects of the metal. It has long been known that temperature has some effect upon the rate of evaporation. It seems quite evident that results obtained from tanks of the type where the water is below the ground surface, especially those of large size, can be more safely extended to the reservoir than results from the tanks with all sides exposed to the air.

The detailed figures of the year's results from this set of tanks are shown in Table II. Figure 4 shows the relation graphically. In the table (also the curve) the evaporation from the largest tank, No. 7, which is 12 feet in diameter, is taken at 100 per cent as a basis for further computation. The actual depths are given in inches as well as percentages. The period from March 6 to November 13, 1916, was such that very little ice interfered with measurements, and the figures shown are evaporation from a free and an open water surface. The percentages for this period run very near to those for the entire year. Over the range of areas 0.785 square foot to 113.1 square feet, or diameters 1 foot to 12 feet, the range in evaporation for the year is 76.18 to 49.16 inches, and in percentage 154.9 to 100 per cent.

At all times when a water surface is free from ice capillarity is pulling the water up on the metal of the tank at all points of the circumference, and wave action also wets the side of the tank, thus adding to the area from which evaporation takes place. These forces may or may not supply the water as fast as it can be evaporated from this wet surface. For the smallest tank this wet strip of metal is 3.14 feet long, or the ratio of this length to the exposed area of the tank is 3.14 to 0.785 = 4.0. This same ratio for the tank 12 feet in diameter is 37.70 to 113.1 = 0.333. Thus, if the wet strips are of the same width, the effect is 12 times as great for the small tank as for the large one. However, wave action will tend to wet a wider strip on the large tank and tend to equalize the effect on the two tanks.

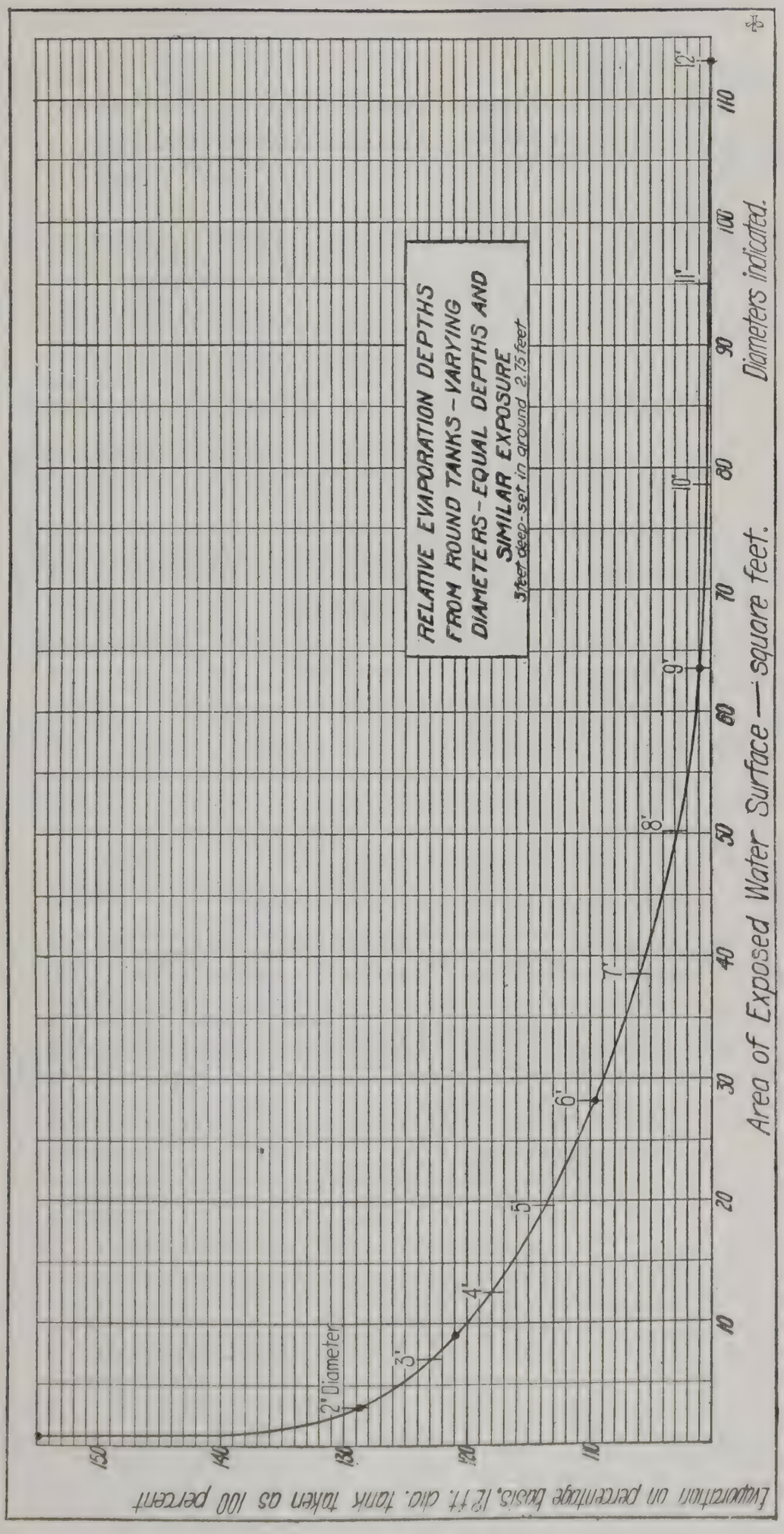

FIG. 4.—Relative evaporation depths from round tanks of varying diameters, equal depths, and similar exposure.

TABLE IV.—*Relation of amount of evaporation to size of exposed area of circular evaporation tanks set in the ground*

Week ending—	Tank 7.		Tank 6.			Tank 5.			Tank 4.			Tank 2.			Tank 1.			Mean air temperature (Maximum + minimum ÷ 2).	Mean relative humidity from hydrograph records.	Total wind movement.
	Evaporation depth.	Mean water temperature.	Evaporation depth.	Evaporation (tank 7, 100 per cent).	Mean water temperature.	Evaporation depth.	Evaporation (tank 7, 100 per cent).	Mean water temperature.	Evaporation depth.	Evaporation (tank 7, 100 per cent).	Mean water temperature.	Evaporation depth.	Evaporation (tank 7, 100 per cent).	Mean water temperature.	Evaporation depth.	Evaporation (tank 7, 100 per cent).	Mean water temperature.			
1915.	*In.*	°F.	*In.*	*P. c.*	°F.	*In.*	*P. c.*	°F.	*In.*	*P. c.*	°F.	*In.*	*P. c.*	°F.	*In.*	*P. c.*	°F.	°F.	*P. c.*	*Miles.*
Nov. 22	0.69	.....	0.73	106	.....	0.64	93	.....	0.71	103	.....	0.86	125	.....	0.96	139	.....	40.6	.....	1,112
29	.70	.....	.73	104	.....	.81	115	.....	.91	130	.....	1.01	144	.....	1.21	173	.....	38.8	.....	1,015
Dec. 6	.25	.....	.27	108	.....	.29	116	.....	.30	120	.....	.32	128	.....	.48	192	.....	38.8	.....	633
13	.43	.....	.42	98	.....	.45	105	.....	.52	121	.....	.55	128	.....	.68	158	.....	39.5	.....	518
1916.																				
Feb. 28[a]	1.21	.....	1.20	99	.....	1.49	123	.....	1.82	.....	.....	1.63	135	.....	1.91	158	.....	.....	.....	.....
Mar. 6	.67	.....	.71	106	.....	.73	109	.....	.77	115	.....	.86	128	.....	.98	146	.....	39.3	.....	853
13	.73	.....	.65	89	.....	.82	112	.....	.89	122	.....	.95	130	.....	1.17	160	.....	46.3	.....	1,273
20	1.00	.....	1.05	105	.....	1.17	117	.....	1.22	122	.....	1.31	131	.....	1.57	157	.....	49.5	.....	731
27	.63	47.6	.64	101	47.8	.72	114	47.5	.76	120	.....	.83	132	47.5	.85	135	.....	46.4	.....	1,022
Apr. 3	.77	47.2	.80	104	48.1	.90	117	48.2	.91	118	46.7	1.07	139	46.9	1.25	162	.....	42.6	.....	807
10	.49	45.8	.51	104	46.2	.60	123	46.0	.52	107	45.7	.65	133	46.8	.59	120	.....	36.4	.....	657
17	.87	52.2	.94	108	52.3	.99	114	51.4	.97	112	51.2	1.09	125	51.8	1.37	158	.....	48.3	.....	897
24	1.04	53.5	1.04	100	53.2	1.18	113	52.4	1.17	113	52.0	1.27	122	52.2	1.48	142	.....	48.7	.....	785
May 1	1.09	54.7	1.16	106	54.7	1.18	108	53.5	1.28	118	53.5	1.32	121	54.0	1.55	142	.....	46.4	.....	870
8	1.19	56.0	1.18	99	56.3	1.33	112	54.7	1.34	113	54.2	1.53	129	55.0	1.66	139	.....	53.9	.....	860
15	1.65	.....	1.69	102	56.5	1.75	106	55.7	1.81	110	56.1	1.96	119	53.7	2.20	133	.....	50.5	60	1,189
22	1.01	53.8	.95	94	54.3	.99	98	.....	1.22	121	53.3	1.24	123	53.3	1.27	126	.....	48.2	71	819
29	2.06	61.2	2.04	99	58.9	2.12	103	60.7	2.45	119	60.0	2.54	123	60.5	2.91	142	.....	58.1	48	1,190
June 5	1.71	66.6	1.77	103	.....	1.89	110	65.2	2.07	121	.....	2.10	123	64.9	2.60	152	.....	61.7	56	634
12	1.61	65.8	1.56	97	.....	1.75	109	64.8	2.13	132	.....	2.05	127	65.0	2.49	154	.....	60.9	62	737
19	1.48	70.4	1.61	109	.....	1.65	110	69.0	1.80	122	.....	1.84	124	69.0	2.41	163	.....	65.0	54	613
26	2.21	69.3	2.24	101	.....	2.36	107	68.0	2.71	123	.....	2.66	120	69.6	3.62	164	.....	67.0	45	834
July 3	2.18	73.2	2.03	93	.....	2.42	111	72.0	2.75	126	.....	2.74	125	76.6	3.53	162	.....	73.6	47	774
10	2.18	73.0	2.09	96	.....	2.29	105	.....	2.68	123	.....	2.69	123	.....	3.54	162	.....	73.6	58	941
17	1.58	.....	1.54	97	.....	1.73	109	.....	1.89	120	.....	2.06	130	.....	2.64	167	.....	69.3	66	500
24	1.83	.....	1.84	100	.....	1.95	107	.....	2.11	115	.....	2.30	125	.....	2.88	137	.....	72.8	61	590
31	1.76	.....	1.72	98	.....	1.93	110	.....	2.08	118	.....	2.26	126	.....	2.76	157	.....	72.7	69	642
Aug. 7	1.40	.....	1.38	99	.....	1.38	99	.....	1.45	104	.....	1.64	117	.....	1.90	140	.....	68.8	78	532
14	1.43	.....	1.48	103	.....	1.54	108	.....	1.51	106	73.8	1.75	122	.....	2.24	157	.....	68.9	71	634
21	1.70	.....	1.69	100	.....	1.83	108	.....	1.96	115	.....	2.15	126	.....	2.57	151	.....	67.2	60	755
28	1.47	.....	1.47	100	.....	1.54	105	.....	1.79	122	.....	1.88	128	.....	2.05	140	.....	62.8	61	620

Sept. 4	1.57	.....	1.63	104	.....	1.69	108	.....	1.90	121	.....	2.17	138	.....	2.67	170	.....	65.5	44	622
11	1.82	.....	1.85	102	.....	2.01	110	.....	2.32	128	.....	2.44	134	.....	2.48	136	.....	66.9	51	882
18	.98	.....	1.05	107	.....	1.17	121	.....	1.22	124	.....	1.33	136	.....	1.64	167	.....	53.2	65	571
25	1.03	.....	1.07	104	.....	1.25	121	.....	1.41	137	.....	1.57	152	.....	1.72	167	.....	58.5	58	555
Oct. 2	1.15	.....	1.18	103	.....	1.28	111	.....	1.46	127	.....	1.48	129	.....	2.22	193	.....	50.5	56	588
9	1.11	.....	1.17	105	.....	1.30	117	.....	1.59	143	.....	1.59	143	.....	1.96	177	.....	51.0	64	849
16	.63	.....	.64	101	.....	.70	111	.....	.76	121	.....	.84	131	.....	1.07	170	.....	44.7	70	824
23	.24	47.0	.25	104	.....	.27	113	47.4	.29	121	48.0	.32	133	.....	.39	162	.....	39.6	73	712
30	.33	44.8	.29	88	.....	.35	106	45.8	.41	124	46.6	.44	132	.....	.59	179	.....	42.8	67	555
Nov. 6	.90	46.7	.99	110	.....	1.00	111	44.4	1.07	119	47.3	1.33	148	.....	1.41	157	.....	51.2	48	700
13	.38	42.6	.38	100	.....	.43	113	39.6	.47	124	41.4	.50	132	.....	.71	187	.....	27.7	70	820
Totals and percentages for year	49.16	.....	49.63	100.9	.....	53.87	109.6	.....	59.40	120.9	.....	63.12	128.7	.....	76.18	154.9	.....	.....	.....	.....
Totals and percentages for period Mar. 6–Nov. 13	45.86	.....	46.28	100.9	.....	50.19	109.5	.....	55.14	120.4	.....	58.85	128.3	.....	70.94	154.7	.....	.....	.....	.....
Mean weekly percentages for year	.....	.....	.....	101.3	.....	.....	110.2	.....	.....	120.8	.....	.....	130.1	.....	.....	156.5	.....	.....	.....	.....
Mean weekly percentages for periods Mar. 6–Nov. 13	.....	.....	.....	101.1	.....	.....	110.2	.....	.....	120.2	.....	.....	129.9	.....	.....	155.5	.....	.....	.....	.....

[a] The total for the period Dec. 13, 1915–Feb. 28, 1916, is shown under date of Feb. 28.

This same ratio holds true for the rim of metal projecting above the ground, mentioned previously. The concentration or radiation effect of this strip of metal is 12 times as great for the small tank as it is for the large one, in proportion to the exposed area of the water. Higher temperatures during the average day and lower temperatures during the average night are reached by the small tank than by the large one. The temperature means are nearly the same, that for the large tank being slightly greater. However, the effect of the higher day temperatures may possibly be greater than that of the lower night temperatures and make the net evaporation due to temperature effect alone greater from the small tank than from the larger. Results from a tank exposed on all sides (No. 8) having a mean temperature lower, a night temperature lower, and a much higher day temperature than No. 7, are consistent with the foregoing statement.

There may be an appreciable vapor blanket effect on evaporation tanks of the size experimented with. An air movement great enough to remove such a covering from a tank 1 foot in diameter would not so quickly change the air above a pan or tank 12 feet in diameter. To pass over the 12-foot diameter in the exact time that is required to pass over the 1-foot diameter would necessitate a wind velocity 12 times as great over the 12-foot tank as over the 1-foot tank, and this variation can not occur. The records of the actual wind velocity for the year show a low velocity of 11.9 miles in 12 hours, or approximately 1.5 feet per second. This occurred once. Eighteen 12-hour periods are recorded having a wind movement of 20 miles or less in 12 hours. The average for the year is 59.5 miles in 12 hours, or approximately 7.5 feet per second. At that rate the largest tank would have a complete change of air covering at intervals of 1.6 seconds. Whether or not this effect is appreciable in the amount of evaporation from tanks of the size used is as yet a matter of opinion. If it is appreciable, then the result would be that of increasing the evaporation from the small tank over that from the large one.

But one previous investigation which would give information as to the ratio sought in the research being described has been made. That was in connection with the extensive study made at Salton Sea for the determination of an evaporation law. In order to compare the results of that with those found at Denver the equipment is described (3, p. 1134):

> In order to test the ratio of evaporation from pans of different sizes, our records include the following combinations: (1) A 4-foot pan self-registered hourly and a 2-foot pan along side on the ground near Tower No. 1; (2) a ow of 3 pans, 2-foot, 4-foot, 6-foot in diameter, on a platform on Tower No. 3, about half a mile from shore, and as near the water as was practicable; (3) a row of 4 pans, 2-foot, 4-foot, 6-foot, 12-foot on a series of adjoining rafts floating in the Salt Creek slue in calm water. The ratios are

quite steady and the results have been incorporated into the final value of the coefficient.

where $C_2=0.023\ (1.23)^n$ for 4-hour intervals.

n =0 for large open water areas,
n =1 for 6-foot pans,
n =2 for 4-foot pans,
n =3 for 2-foot pans,
n =4 for ordinary dry air.

The value of the coefficient for n=1 is fairly well determined, and is interpolated for n=4. These should be further verified if possible.

It will be noted from this extract and by a reference to the original work (3) that the pans used are of the type that is almost entirely exposed. The sides of the pans on rafts may have been partly water-covered. The results are not exactly comparable with those obtained at the Denver laboratory; nor would it appear that they could be as safely extended to large water bodies. A comparison on the basis that the results from the 6-foot tanks of each investigation are the same is given in Table III.

TABLE III.—*Ratio of evaporation at the Denver laboratory and at Salton Sea*

Test.	Denver laboratory.	Salton Sea.
Ordinary dry air	.....	209
1-foot tank	155	.....
2-foot tank	129	163
4-foot tank	118	125
6-foot tank	110	110
9-foot tank	101	.....
12-foot tank	100	.....
Large open-water area	.....	87

The extension of the results obtained at the Denver laboratory to larger water surfaces is discussed later.

RELATION BETWEEN EVAPORATION FROM CIRCULAR TANKS AND SQUARE TANKS SET IN THE GROUND OF EQUAL EXPOSED WATER SURFACE

Tank 4 is circular, with a diameter of 3.39 feet and an area of 9.0 square feet; tank 3 is 3 feet square; tank 2 is circular, with a diameter of 2 feet and an area of 3.14 square feet; tank 15 is 1.77 feet square. All are 3 feet deep and are set in the ground. Table IV shows the evaporation figures for these tanks. Based upon the totals, the evaporation from the larger square tank is 102.7 per cent of that from the circular one of the same area; that from the other square one is 103.5 per cent of that from the circular one of the same exposed area. Based upon mean weekly averages, these figures are 104.7 and 104.9.

TABLE IV.—*Relation between evaporation from square and circular tanks of the same surface area and depth. All tanks 3 feet deep, set in ground 2.75 feet*

Week ending—	Evaporation from tank 4.	Evaporation from tank 3.	Evaporation from tank 3 expressed as a percentage of that from tank 4.	Evaporation from tank 2.	Evaporation from tank 15.	Evaporation from tank 15 expressed as a percentage of that from tank 2.
1915.	*Inches.*	*Inches.*	*Per cent.*	*Inches.*	*Inches.*	*Per cent.*
Nov. 22	0.71	0.84	118	.....	.....	.....
29	.91	.99	108	.....	.....	.....
Dec. 6	.30	.29	97	.....	.....	.....
13[a]	.52	.45	87	.....	.....	.....
1916.						
Feb. 28	1.82	1.86	102	.....	.....	.....
Mar. 6	.77	.89	115	.....	.....	.....
13	.89	.92	103	.....	.....	.....
20	1.22	1.26	103	.....	.....	.....
27	.76	.76	100	.....	.....	.....
Apr. 3	.91	.97	107	.....	.....	.....
10	.52	.59	113	.....	.....	.....
17	.97	1.12	116	.....	.....	.....
24	1.17	1.20	103	1.27	1.25	99
May 1	1.28	1.33	104	1.32	1.36	103
8	1.34	1.48	110	1.53	1.52	99
15	1.81	1.91	105	1.96	2.07	106
22	1.22	1.11	91	1.24	1.18	95
29	2.45	2.46	100	2.54	2.69	106
June 5	2.07	2.11	102	2.10	2.34	111
12	2.13	2.03	95	2.05	2.22	108
19	1.80	1.90	106	1.84	1.93	105
26	2.71	3.01	111	2.66	2.80	105
July 3	2.75	2.92	106	2.74	2.79	102
10	2.68	2.79	104	2.69	2.92	109
17	1.89	1.99	105	2.06	2.05	100
24	2.11	2.34	111	2.30	2.28	99
31	2.08	2.16	104	2.26	2.35	104
Aug. 7	1.45	1.61	111	1.64	1.55	95
14	1.51	1.72	114	1.75	1.80	103
21	1.96	2.04	104	2.15	2.14	100
28	1.79	1.75	98	1.88	1.78	95
Sept. 4	1.90	2.05	108	2.17	2.20	101
11	2.32	2.17	96	2.44	2.47	101
18	1.22	1.29	106	1.33	1.39	105
25	1.41	1.39	99	1.57	1.62	103
Oct. 2	1.46	1.53	105	1.48	1.70	115
9	1.59	1.51	95	1.59	1.70	107
16	.76	.86	113	.84	.90	107
23	.29	.31	107	.32	.40	125
30	.41	.43	105	.44	.57	130
Nov. 6	1.07	1.23	115	1.33	1.40	105
13	.47	.50	106	.60	.63	105
Total[b]	59.40	62.07	104.5	52.09	54.00	103.7
Percentage[c]	.....	.....	104.9	.....	.....	104.9

[a] From Dec. 13, 1915, to Feb. 28, 1916, weekly records were not possible.
[b] Totals and percentages are based upon these totals.
[c] Mean weekly percentages.

In the case of the 9 square-foot area the ratio, perimeter divided by area, is 0.15 greater in the case of the square tank than for the circular one. This has apparently caused an increase in evaporation of 2.7 per cent. For the tanks of 3.14 square feet area there is a corresponding increase of 0.26 in the ratio and an increase of 3.5 per cent in evaporation.

Although these figures do not show the exact relation, the comparison between the results from round and square tanks is sufficient to show that the great difference in the ratio, perimeter to area, for tanks ranging from 1 foot to 12 feet in diameter has an important part in the difference in evaporation depths from these tanks. No difference in mean water temperature could be measured between tanks 2 and 15, and 3 and 4.

VARIATION OF EVAPORATION WITH DEPTH OF TANK SET IN THE GROUND

Tanks 18 to 22 and tank 3 are 2 feet in diameter. They range in depth of water from 0.25 foot to 5.75 feet. Tanks 16 and 17 are 6 feet in diameter and, taken with No. 5, the set of three range in depth of water from 0.75 foot to 2.75 feet. These two sets were installed quite late in the season (May 25), but the results are representative. Table V shows the weekly evaporation depths for the nine tanks and the ratio of the evaporation from the tanks of lesser depth to that from the deepest of each set, expressed as a percentage. It is quite evident that the difference in evaporation over the range of depths is due to temperature. During the months when the cooling effects of the night were not so great, the shallow tanks show the greater evaporation; but later, when the day temperatures and the heat storage of the shallow tanks are more than offset by the low night temperatures, the shallow tanks indicate a lesser evaporation.

This difference in evaporation is not great, but for general use a tank not less than 2 feet deep is recommended, since its contents will not become heated or cool as quickly as those of the shallower tank. The difference between the results from the 6-foot tank and the 3-foot one is so slight that under all ordinary conditions there is no necessity for using a tank deeper than 3 feet. The evaporation as measured from tanks from 2 to 3 feet in depth may be more safely extended to the reservoir than that from shallower tanks, since the deeper tanks operate more in accordance with the reservoir under natural conditions.

TABLE V.—*Relative depths of evaporation from tanks of the same diameter and varying depths*

Week ending—	Tanks all 2 feet in diameter.											Tanks all 6 feet in diameter.					
	Evaporation from tank 18, water 5.75 feet deep.	Evaporation from tank 2, water 2.75 feet deep.	Evaporation from tank 2, expressed as a percentage of that from tank 18.	Evaporation from tank 19, water 1.75 feet deep.	Evaporation from tank 19, expressed as a percentage of that from tank 18.	Evaporation from tank 20, water 1.25 feet deep.	Evaporation from tank 20, expressed as a percentage of that from tank 18.	Evaporation from tank 21, water 0.75 foot deep.	Evaporation from tank 21, expressed as a percentage of that from tank 18.	Evaporation from tank 22, water 0.25 foot deep.	Evaporation from tank 22, expressed as a percentage of that from tank 18.	Evaporation from tank 5, water 2.75 feet deep.	Evaporation from tank 16, water 1.75 feet deep.	Evaporation from tank 16, expressed as a percentage of that from tank 5.	Evaporation from tank 17, water 0.75 foot deep.	Evaporation from tank 17, expressed as a percentage of that from tank 5.	Mean air temperature.[a]
1916.	*Inches.*	*Inches.*	*Per cent.*	*Inches.*	*Per cent.*	*Inches.*	*Per cent.*	*Inches.*	*Per cent.*	*Inches.*	*Per cent.*	*Inches.*	*Inches.*	*Per cent.*	*Inches.*	*Per cent.*	°F.
June 12	1.36	2.05	104	2.05	104	2.04	104	2.09	107	2.18	111	1.75	1.68	96	1.73	99	61
19	1.92	1.84	96	1.90	99	1.84	96	1.98	103	2.21	115	1.65	1.75	106	1.76	106	65
26	2.87	2.66	93	2.89	101	2.92	102	2.97	103	3.05	106	2.36	2.38	101	2.52	107	67
July 3	2.85	2.74	96	2.94	103	2.93	103	3.05	107	2.95	104	2.42	2.43	101	2.45	101	74
10	2.77	2.69	97	2.76	100	2.85	103	2.84	103	2.82	102	2.29	2.32	101	2.34	102	74
17	2.03	2.06	101	2.07	102	2.11	104	2.11	104	2.10	103	1.73	1.69	98	1.76	102	69
24	2.37	2.30	97	2.33	98	2.31	97	2.32	98	2.36	100	1 95	1.95	100	1.94	99	73
31	2.28	2.26	99	2.28	100	2.24	98	2.22	97	2.23	98	1.93	1.96	101	1.88	98	73
Aug. 7	1.69	1.64	97	1.61	95	1.69	100	1.78	105	1.69	100	1.38	1.41	102	1.40	101	69
14	1.74	1.75	101	1.76	101	1.72	99	1.76	101	1.85	107	1.54	1.53	100	1.56	101	69
21	2.07	2.15	104	2.04	99	2.04	99	2.03	98	2.05	99	1.83	1.78	97	1.75	96	67
28	1.85	1.88	102	1.76	95	1.69	91	1.73	94	1.72	93	1.54	1.52	99	1.49	97	63
Sept. 4	2.17	2.17	100	2.07	95	1.98	91	1.86	86	2.00	92	1.69	1.53	91	1.68	100	66
11	2.43	2.44	100	2.33	96	2.21	91	2.13	88	2.17	89	2.01	1.89	94	1.74	87	67
18	1.39	1.33	96	1.23	89	1.17	84	1.13	81	1.03	74	1.17	1.02	87	1.00	85	53
25	1.62	1.57	97	1.47	91	1.44	89	1.45	90	1.45	90	1.25	1.15	92	1.18	94	58
Oct. 2	1.53	1.48	97	1.50	98	1.42	93	1.39	91	1.37	90	1.28	1.18	92	1.14	89	50
9	1.59	1.59	100	1.52	96	1.42	89	1.44	91	1.38	87	1.30	1.19	92	1.16	89	51
Total	37.13	36.60	98.6	36.51	98.3	36.02	97	36.28	97.7	36.61	98.6	31.07	30.36	97.8	30.48	98.1	.....

[a] From maximum and minimum thermometers.

EVAPORATION FROM FLOWING WATER

Early in July tank 26 was installed. This and No. 15 are of equal depth and exposed water area. Installation was made so that the exposure would be similar. They were located about 25 feet apart. A motor-driven centrifugal pump kept the surface water of No. 26 flowing. No. 15 was motionless. Thermometers were placed in each tank. Owing to a lack of means of preventing slopping, a surface volocity of 1.44 feet per second was all that could be attained.

Table VI gives the results of this investigation. These final figures were arrived at after the application of a temperature correction. Data for making this correction were obtained by the use of the special set of tanks, No. 21, 23, 24, and 25. They are all of the same depth and diameter. By the immersion of electric-light bulbs in them, a variation of surface temperatures was obtained. The weekly data on this work are recorded in Table VI. Plate 36, *B*, shows one of these tanks.

TABLE VI.—*Relation between the amounts of evaporation from a tank of flowing water and a tank of still water; tanks of equal exposed area, depth, and similar exposure. Exposed water surface 1.77 feet square; depth of tank 3 feet*

Date.	Length of run.	Evaporation from tank 15, still water.	Evaporation from tank 26, flowing water. Corrected for temperature increase.	Surface velocity of flowing water.
	Hours.	*Inch.*	*Inch.*	*Feet per sec.*
July 13	12	0.15	0.17	0.68
17	12	.22	.23	.68
18	12	.16	.19	.68
19	5½	.04	.04	.84
20	12	.24	.22	.84
21	12	.32	.29	.84
22	12	.34	.32	.84
23	12	.25	.26	.84
29	6¾	.12	.20	.98
Aug. 1	12	.13	.16	.98
2	12	.21	.22	.98
July 24	12	.24	.32	1.05
24–5	11	.18	.25	1.05
25	12	.24	.30	1.05
26	12	.21	.27	1.05
Aug. 16	8½	.11	.12	1.11
17	12	.24	.30	1.44
Total [a]	.....	3.40	3.86	.....

[a] Ratio, $\frac{\text{flowing}}{\text{still}} = \frac{3.86}{3.40} = 1.072$.

However, for making the temperature correction on the flowing-water data the temperature figures of corresponding days were used and not averages. An example will illustrate the method; July 13 will be taken.

Observed mean temperature for tank 15, 75°; evaporation, 0.15 inch.
Observed mean temperature for tank 26, 85°; evaporation, 0.24 inch.
Observed mean temperature for tank 21, 75°; evaporation, 0.12 inch.
Observed mean temperature for tank 23, 81°; evaporation, 0.27 inch.
Observed mean temperature for tank 24, 85°; evaporation, 0.32 inch.
Observed mean temperature for tank 25, 93°; evaporation, 0.43 inch.

It happens in this case that no interpolation is necessary, since the exact temperature of tanks 15 and 26 are found in the other set. Whenever interpolation was necessary it was done by means of a curve. The increase in evaporation caused by the 10° from 75 to 85, tanks 21 and 24, is 45 per cent of that from the tank of lower temperature. By assuming that this relation holds for the other tanks the observed figures should be reduced by 45 per cent of 0.15 or 0.07 inch, or the corrected evaporation from tank 26 is 0.17 inch.

During the latter part of August tanks 67 and 68 were installed. The installation is shown in Plate 36, *A*. The velocities in this experiment also had to be kept low. Table VII gives the final results, the correction for temperature being made in the manner described above.

TABLE VII.—*Relation between amounts of evaporation from a tank of flowing water and a tank of still water; tanks of equal exposed area, depth of water, and with similar exposure. Exposed water surface 1 foot by 25 feet; water about 3 feet deep*

Date	Length of run.	Evaporation from tank 68, still water.	Evaporation from tank 67, flowing water. Corrected for increased temperature.	Surface velocity of flowing water.
1916.	*Hours.*	*Inch.*	*Inch.*	*Feet per sec.*
Aug. 28	12	0.17	0.22	0.52
25	8	.13	.13	.62
Sept. 1	12	.24	.23	.65
Aug. 29	8½	.10	.11	.67
Sept. 7	6¾	.11	.11	.71
13	12	.22	.23	.72
16	5	.07	.07	.79
14	12	.11	.14	.81
Oct. 1	8	.11	.16	.84
Aug. 30	5¼	.10	.10	.88
Sept. 8	12	.37	.32	.94
2	12	.28	.32	.95
25	12	.14	.18	.95
Oct. 2	10	.13	.14	.96
Sept. 6	9½	.23	.26	1.07
7	8½	.18	.20	1.25
Total [a]	.....	2.69	2.92	.....

[a] Ratio, $\frac{\text{flowing}}{\text{still}} = \frac{2.92}{2.69} = 1.086$.

The figures show that for the first set of tanks evaporation from the flowing water was 107 per cent of that from the still water under exactly the same conditions. For the other set, a tank 25 feet long, the evaporation from the flowing water was 108 per cent of that from still water. While this experiment was limited because of the low water velocity, it would tend to show that evaporation loss from a canal would be slightly greater than from a still body of water under exactly the same conditions

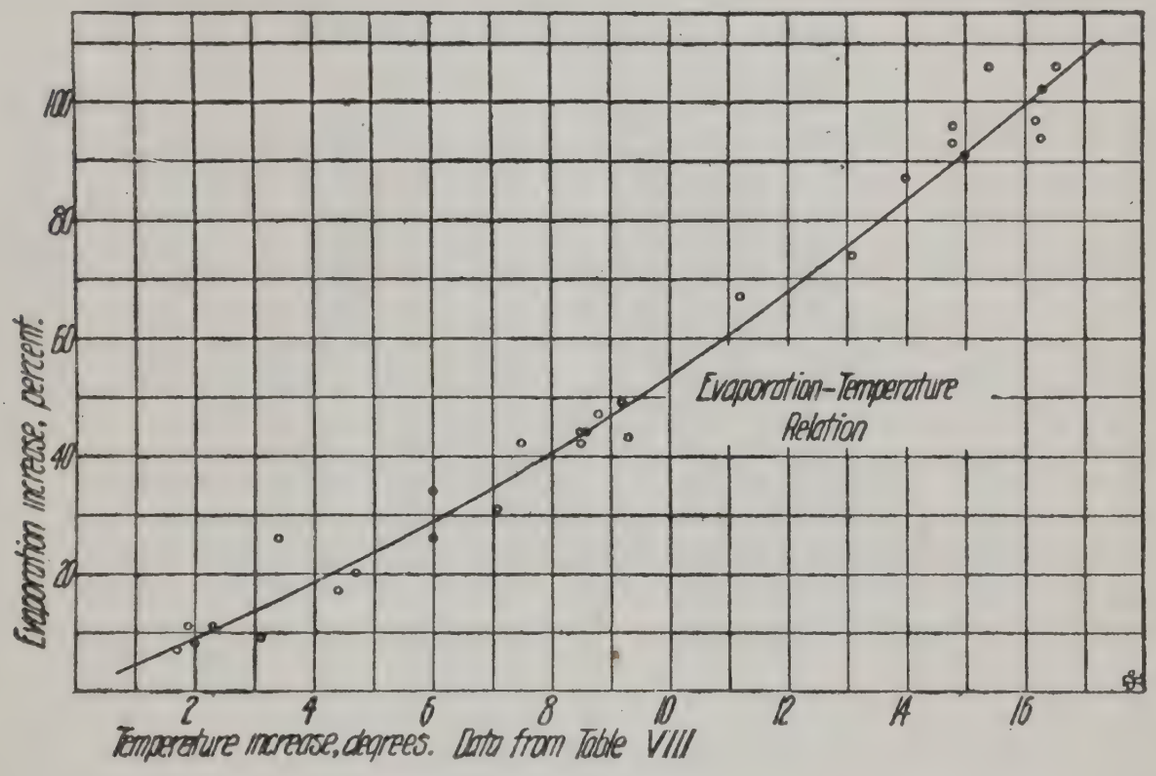

FIG. 5.—Relation of evaporation and temperature, all other factors being similar.

of exposure, temperature of water, etc. There seems to be no definite relation between evaporation and velocity within the limits of the experiment.

The only previous work in this connection noted is that carried out in Spain in 1849 (4), which for the short period of the experiment indicated an evaporation from moving water, agitated but not flowing, of 140 per cent of that from still water. Temperature effect was not considered in this, so far as can be learned.

EFFECT OF TEMPERATURE UPON EVAPORATION

As has been noted previously, the temperature effect upon evaporation was observed, primarily, for calibration by means of similar tanks heated to different temperatures. Thus, the variable is temperature, all other factors remaining the same. Figure 5 shows graphically the results indicated in Table VIII.

TABLE VIII.—*Relation of evaporation from small water surface to temperature of water surface, all other conditions being similar*

Week ending—	Evaporation from tank 21.	Mean temperature of water surface.	Evaporation from tank 23.	Mean temperature of water surface.	Degrees higher than No. 21.	Evaporation from tank 23, expressed as percentage of that from No. 21.	Evaporation from tank 24.	Mean temperature of water surface.	Degrees higher than No. 21.	Evaporation from tank 24, expressed as percentage of that from No. 21.	Evaporation from tank 25.	Mean temperature of water surface.	Degrees higher than No. 21.	Evaporation from tank 25, expressed as percentage of that from No. 21.
1916.	*In.*	°*F.*	*In.*	°*F.*		*Per ct.*	*In.*	°*F.*		*P. ct.*	*In.*	°*F.*		*Per ct.*
July 17	2.11	72.3	2.48	76.7	4.4	117	3.03	80.8	8.5	144	4.02	87.3	15.0	191
24	2.32	71.5	2.78	76.2	4.7	120	3.45	80.7	9.2	149	4.05	84.6	13.1	174
31	2.22	73.4	2.47	75.7	2.3	111	2.82	79.4	6.0	126	.....	.....	.....	.....
Aug. 7	1.78	71.7	1.94	74.8	3.1	109	2.33	78.8	7.1	131	2.54	81.0	9.3	143
14	1.76	72.1	1.95	74.0	1.9	111	2.94	83.3	11.2	167	3.66	86.5	14.4	208
21	2.03	69.8	2.24	71.5	1.7	107	2.73	75.8	6.0	134	3.92	84.6	14.8	193
28	1.73	67.8	1.86	69.8	2.0	108	.....	.....	.....	.....	3.57	83.2	15.4	206
Sept. 4	1.86	66.6	2.34	70.0	3.4	126	.....	.....	.....	.....	3.65	81.4	14.8	196
11	2.13	67.3	.....	.....	.....	.....	3.03	74.8	7.5	142	3.98	81.3	14.0	187
18	1.13	57.0	.....	.....	.....	.....	1.88	65.7	8.7	167	2.49	73.3	16.3	220
25	1.45	59.7	.....	.....	.....	.....	2.13	68.5	8.8	147	2.98	76.3	16.6	206
Oct. 2	1.39	56.5	.....	.....	.....	.....	1.97	65.0	8.5	142	2.70	72.8	16.3	194
9	1.44	54.2	.....	.....	.....	.....	2.08	62.8	8.6	144	2.83	70.4	16.2	197

In this connection attention is called to Table IX, showing temperatures at different points from the top to the bottom of the deeper tanks in use at the laboratory. The first set of temperatures recorded were early in the season, before the lower water had become warm, but on a warm day. The second measurement, on a cold day in May, shows how the whole water body has warmed up, and, though the air temperature is low, the heat storage effect of the water keeps its temperature above that of the air. Similar variations throughout the season are of interest. The temperature variations in the different-sized tanks are also brought out.

TABLE IX.—*Water temperatures at different depths in evaporation tanks and lake*

Date.	Depth below surface.	Air temperature.[a]	Water temperature (°F.).									
			Tank 7.	Tank 6.	Tank 5.	Tank 4.	Tank 2.	Tank 1.	Lake and tank 9.	Tank 18.	Tank 20.	Tank 22.
1916.	*Feet.*	°F.										
Mar. 27	0.05	69	59	60	62	61	63	.....	.....	.....	.....	.....
	.25	.....	53	56	56	56	58	.....	.....	.....	.....	.....
	.5	.....	49.5	53	50	50	51	.....	.....	.....	.....	.....
	.75	.....	48	49	47.5	48	47.5	.....	.....	.....	.....	.....
	1	.....	47	46	46	46.5	46	.....	.....	.....	.....	.....
	1.5	.....	46.5	45	44.5	46	45	.....	.....	.....	.....	.....
	2	.....	46.5	45	47	45.5	44	.....	.....	.....	.....	.....
	2.5	.....	46.5	44.8	44	45	44	.....	.....	.....	.....	.....
	2.75	.....	.....	.....	.....	45	44	.....	.....	.....	.....	.....
May 12	.05	45	.....	56	55.5	55	55	.....	.....	.....	.....	.....
	.25	.....	.....	56	55.5	55	55	.....	.....	.....	.....	.....
	.5	.....	.....	56	55.5	55.5	55	.....	.....	.....	.....	.....
	.75	.....	.....	56	55.5	55.5	55.5	.....	.....	.....	.....	.....
	1	.....	.....	56	55.5	55.5	55.5	.....	.....	.....	.....	.....
	1.5	.....	.....	56	55	55	54.5	.....	.....	.....	.....	.....
	2	.....	.....	56	55	55	54.5	.....	.....	.....	.....	.....
	2.5	.....	.....	56	55	55	54	.....	.....	.....	.....	.....
June 16	.05	73–76	71	72	.....	71.6	72.5	76.5	74	71.5	71.5	80.2
	.25	.....	69.5	70.1	.....	70.6	70	75	73.7	69.8	70	80.8
	.5	.....	69.3	70	.....	68.7	68	71	73.7	67.7	68.8	.....
	.75	.....	69	69.5	.....	68	67.5	69	73.7	.....	68.8	.....
	1	.....	69	69	.....	67.5	66.75	68	73.7	66.5	68.5	.....
	1.5	.....	69	68.8	.....	66.6	65.8	67	.....	66	.....	.....
	2	.....	69	68.8	.....	66.1	65.2	65.8	73.4	65.2	.....	.....
	2.5	.....	69	68.8	.....	66	64.8	65.3	.....	64.5	.....	.....
	3	.....	.....	.....	.....	.....	.....	.....	73	64	.....	.....
	4	.....	.....	.....	.....	.....	.....	.....	71	63.8	.....	.....
	5	.....	.....	.....	.....	.....	.....	.....	70.5	63.8	.....	.....
	6	.....	.....	.....	.....	.....	.....	.....	70	.....	.....	.....
	6.9	Bottom.	.....	.....	.....	.....	.....	.....	70	.....	.....	.....
June 29	.05	94	77.5	76.6	77.5	.....	81	.....	.....	.....	79	81
	.25	.....	77.5	77	78	.....	80.5	.....	76.8	.....	79.2	81.2
	.5	.....	77.5	77	78.2	.....	79.6	.....	76.8	.....	79.5	.....
	.75	.....	77.5	76.6	75.6	.....	77	.....	76.5	.....	79.5	.....
	1	.....	77.3	74.5	74	.....	75	.....	75	.....	79.5	.....
	1.5	.....	77.3	72.5	74	.....	73	.....	73	.....	.....	.....
	2	.....	77.3	71.5	73.5	.....	72	.....	72	.....	.....	.....
	2.5	.....	77.3	71	73.5	.....	71	.....	70.5	.....	.....	.....
	3	.....	.....	.....	.....	.....	.....	.....	70.5	.....	.....	.....
	4	.....	.....	.....	.....	.....	.....	.....	70	.....	.....	.....
	5	.....	.....	.....	.....	.....	.....	.....	69.8	.....	.....	.....
Sept. 1	.05	80–84	70	70	70	70.5	71.6	77	74	73	73.5	81.5
	.25	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	81.5
	.5	.....	69	69	68.4	68	69.4	72	72	72	70.6	.....
	.75	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	1	.....	68	68	67.2	66.5	67	68.5	72	69	69.5	.....
	1.5	.....	68	67.5	66.5	65.6	66	67.5	72	68	.....	.....
	2	.....	68	67.5	66.2	65.4	65.2	66.7	71.5	67.2	.....	.....
	2.5	.....	68	67.2	66.2	65	65	66.5	70	66.5	.....	.....
	2.75	.....	68	67.7	66.5	65.5	65.5	66.5	.....	66	.....	.....
	3	.....	.....	.....	.....	.....	.....	.....	69.5	66	.....	.....
	4	.....	.....	.....	.....	.....	.....	.....	69	.....	.....	.....
	5	.....	.....	.....	.....	.....	.....	.....	69	.....	.....	.....
	6	.....	.....	.....	.....	.....	.....	.....	68	.....	.....	.....
	7.5	.....	.....	.....	.....	.....	.....	.....	67	.....	.....	.....
Sept. 27	.05	56	56.5	56.5	55.5	56	57.2	59	.....	.....	.....	.....
	.25	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	.5	.....	57	57	55.7	56.2	57	59	.....	.....	.....	.....
	.75	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	1	.....	57.2	57	56	56.2	57	59	.....	.....	.....	.....
	1.5	.....	57.3	57.1	56	56.5	57.1	59	.....	.....	.....	.....
	2	.....	57.4	57.2	56	56.5	57.2	59	.....	.....	.....	.....
	2.5	.....	58	57.7	58	56.5	58.5	59	.....	.....	.....	.....

[a] Temperature in instrument shelter.

UNITED STATES WEATHER BUREAU STANDARD PAN FOR CLASS A STATIONS

Plate 37, *A*, shows the United States Weather Bureau standard pan as specified for class A stations. This is also shown as *A*, figure 3. The

pan was installed in November, 1915, emptied for the winter, refilled in March, 1916, and used throughout the year ending in November, 1916. Table X presents figures from this pan in comparison with the evaporation with tank 7. Based upon the totals during the time of use of the pan, evaporation from it was exactly 1½ times that from the large pan sitting in the ground. In extension to large water surfaces this figure would be safe to use under conditions similar to those at Denver. However, since the pan departs so greatly from the reservoir, in that its whole water body is above the ground and is subjected to effects of radiation and heat concentration, no statement can be made regarding the application of the figure (1½) to other locations. Temperature records show a very much higher day temperature, a somewhat lower night temperature, and a lower mean temperature for this tank than any set in the ground. It follows more closely the variations in air temperature than any of the other tanks used except the very shallow ones.

TABLE X.—*Relation between evaporation from tank 7 (12 feet in diameter by 3 feet in depth, set in ground 2.75 feet) and a Weather Bureau standard pan (tank 8) for class A station, under same conditions*

Week ending—	Evaporation from tank 7.	Evaporation from tank 8.	Evaporation from tank 8, expressed as percentage of that from tank 7.	Week ending—	Evaporation from tank 7.	Evaporation from tank 8.	Evaporation from tank 8, expressed as percentage of that from tank 7.
1915.	*In.*	*In.*	*P. ct.*	1916.	*In.*	*In.*	*P. ct.*
Nov. 22	0.69	1.00	145	July 3	2.18	3.89	178
29	.70	1.23	175	10	2.18	3.04	140
Dec. 6	.25	.42	168	17	1.58	2.64	167
13 [a]	.43	.76	176	24	1.83	2.71	148
1916.				31	1.76	2.66	157
Mar. 6	.67	.99	148	Aug. 7	1.40	1.97	141
13	.73	1.21	166	14	1.43	2.09	146
20	1.00	1.78	178	21	1.70	2.37	139
27	.63	.98	156	28	1.47	1.92	131
Apr. 3	.77	1.03	136	Sept. 4	1.57	2.24	143
10	.49	.63	129	11	1.82	2.45	135
17	.87	1.53	176	18	.98	1.33	136
24	1.04	1.55	144	25	1.03	1.80	175
May 1	1.09	1.59	146	Oct. 2	1.15	1.54	133
8	1.19	2.05	172	9	1.11	1.63	147
15	1.65	2.19	133	16	.63	1.09	174
22	1.01	1.49	148	23	.24	.36	150
29	2.06	2.89	140	30	.33	.50	151
June 5	1.71	2.50	146	Nov. 6	.90	1.30	145
12	1.61	2.27	135	13	.38	.60	158
19	1.48	2.42	163				
26	2.21	3.31	150	Total [b]	47.95	71.95	.....

[a] Record broken. No. 8 was emptied on December 14 because of ice, and filled on February 29.
[b] Total evaporation from tank 8 expressed in percentage of that from tank 7, 150.0. Mean weekly percentage, 151.8.

PICHE EVAPORIMETER

The Piche evaporimeter used is of the so-called improved type, having a vent tube through the center opening at the top. It is graduated in cubic centimeters, having a capacity of 40 c. c. The glass plate is 9 cm. in diameter. It was hung in the instrument shelter.

Table XI shows the evaporation figures resulting from its use. These were not reduced to actual depths. A direct ratio between the evaporation (in cubic centimeters) from the Piche instrument and tank 7 was found in order to show the consistency of the results. Wind velocities seem to have no direct bearing on this ratio.

Previous experiments (1, p. 254) have been such as to warrant the statement, "Estimated its accuracy as correct within 20 per cent." The data of the writers tend to show that the statement is not too conservative. Its use is not recommended when another type of evaporimeter can be used, as it requires attention at more frequent intervals than other types of evaporation-measuring devices. On particularly dry days the tube would be empty within six hours after filling, and at such times, while the tube contained water, this water could not flow to the filter paper surface fast enough to prevent the drying and curling of the edge.

TABLE XI.—*Relation between evaporation from water surface tank 7 (12 feet in diameter by 3 feet in depth) and the Piche evaporimeter, Weather Bureau type*

Week ending—	Evaporation from tank 7.	Evaporation as shown by Pische mevaporieter.	Pische evaporation record ÷depth from No. 7.	Variation from mean ratio.	Wind movement.
1916.	*Inches.*	*C. c.*		*P. ct.*	*Miles.*
Apr. 24 [a]	1.04	187.0	180	− 0.9	860
July 24	1.83	368.9	201	+10.6	590
31	1.76	319.4	180	− .9	642
Aug. 7	1.40	181.8	130	−28.5	532
14	1.43	223.8	156	−14.2	634
21	1.70	280.8	165	− 9.2	755
28	1.47	217.6	148	−18.6	620
Sept. 4	1.57	328.8	209	+15.0	622
11	1.82	361.0	198	+ 9.5	882
18	.98	156.0	159	−12.5	571
25	1.03	266.2	259	+42.6	555
Oct. 2	1.15	225.7	196	+ 7.9	588
Total [b]	17.18	3,117.0	[c] 181.7	.....	.....

[a] Records broken until July 17.

[b] Ratio of totals, $\frac{3117.0}{17.8} = 181.3$.

[c] Mean weekly ratio.

EXTENSION OF THE EVAPORATION DEPTHS FROM LAND PANS TO LARGER OPEN-WATER SURFACES UNDER THE SAME CONDITIONS BY USE OF A FLOATING PAN

A part of Washington Park, South Denver, is shown in figure 1. The lake is artificial, material from the excavation having been taken to form an embankment for the west and southwest sides. The other shores are natural. The water level is maintained by the supply from the city ditch. There is no outlet, but seepage is great. It has been the custom to cut off the water supply late in the fall, and by spring, when water was again turned in, but a small pond would be left. The area of the lake is about 17 acres; the depth at the south and southeast is 3 to 4 feet and 5 to 8 feet north of the island; a maximum of 7.6 feet was measured at the point indicated by the star.

The contours give an idea of the exposure; some groups of trees are located about the lake, but these are still small. Plate 37, *B*, looking southeast, shows the character of these tree obstructions. The mean elevation of the water surface was for the season, 5,310.3 feet, or 36 feet lower than the highest point of the laboratory.

Evaporation tank 9, United States Geological Survey floating standard, was installed as soon as water was let into the pond in the spring, and the records show the dates of its use. The pan itself floated free in a 6-foot inclosure of the protecting raft. This raft was 16 feet square and was built of 8-inch material standing on edge. It proved an effective baffle for the wave action on this small reservoir. Four casks, one at each corner, were necessary, as the lumber became water soaked toward the end of the season. The raft, with floating tank, anemometer, and rain gage, was anchored at the point indicated by the star, 3,400 feet from the laboratory. The tank was reached by canoe. Observations were made on water temperature, wind, precipitation, and evaporation. No boats are allowed on the lake, and swimmers are not permitted to use it; thus, the evaporation pan was free from interference. Plate 37, *B*, shows a still well; this was later removed (after two weeks' use), and observations were taken when there was little wind movement.

Tabulated results of the season's observations are given in Table XII.

Evaporation as measured from the floating pan was for the season, 108.9 per cent of that from the 12-foot land pan at the laboratory and 86.1 per cent of that from a 3-foot square pan (equal in area and of similar shape to the floating) at the laboratory.

TABLE XII.—*Relation between evaporation from United States Geological Survey standard floating pan and land pans*

Week ending—	Evaporation from tank 7, land.[a]	Mean temperature of water at surface, No. 7.	Evaporation from tank 3, land.[b]	Evaporation from tank 3 expressed as a percentage of that from No. 7.	Mean temperature of water at surface, No. 3.	Evaporation from tank 9.[c]	Evaporation from tank 9 expressed as a percentage of that from No. 7.	Mean temperature of water at surface, No. 9.	Evaporation from tank 3 expressed as a percentage of that from No. 9.	Wind movement on lake.	Wind movement at laboratory.
1916.	*Inches.*	*° F.*	*Inches.*	*Per cent.*	*° F.*	*Inches.*	*Per cent.*	*° F.*	*Per cent.*	*Miles.*	*Miles.*
Apr. 24	1.04	53.5	1.20	115	52.0	1.04	100	.....	115	820	785
May 1	1.09	54.7	1.33	122	53.8	1.13	104	.....	118	926	870
8	1.19	56.0	1.48	124	53.7	1.15	97	58.2	129	928	860
15	1.05	.....	1.91	116	55.6	1.66	100	59.5	115	1,212	1,189
22	1.01	53.8	1.11	110	52.9	1.01	100	56.3	110	982	819
29	2.06	61.2	2.46	119	59.8	2.10	102	.....	117	.....	1,190
June 5	1.71	66.6	2.11	123	64.0	1.95	104	.....	108	715	634
12	1.61	65.8	2.03	126	63.5	1.78	107	67.2	117	778	737
19	1.48	70.4	1.90	128	67.4	1.75	118	70.2	108	691	613
26	2.21	69.3	3.01	136	66.7	2.45	111	70.1	123	723	834
July 3	2.18	73.2	2.92	134	71.6	2.46	113	79.5	119	704	774
10	2.18	73.0	2.79	128	71.4	2.50	115	74.1	111	905	941
17	1.58	.....	1.99	126	72.0	1.75	111	74.5	114	496	500
24	1.83	.....	2.34	128	72.0	2.02	110	75.7	116	597	590
31	1.76	.....	2.16	123	73.5	2.14	121	76.3	101	673	642
Aug. 7	1.40	.....	1.61	115	72.6	1.56	111	74.9	103	603	532
14	1.43	.....	1.72	120	72.2	1.57	110	75.8	109	619	634
21	1.70	.....	2.04	120	71.1	1.74	102	74.2	117	689	755
28	1.47	.....	1.75	119	68.7	1.57	107	71.7	111	635	620
Sept. 4	1.57	.....	2.05	131	67.4	1.70	108	68.8	120	672	622
11	1.82	.....	2.17	119	68.3	1.96	108	68.6	111	1,470	882
18	.98	.....	1.29	132	58.6	1.06	108	64.2	122	.....	571
25	1.03	.....	1.39	135	60.7	1.13	110	62.6	123	521	555
Oct. 2	1.15	.....	1.53	133	57.7	1.37	119	59.3	112	632	588
9	1.11	.....	1.51	136	55.9	1.14	102	56.7	132	840	849
16	.63	.....	.86	137	50.3	.67	106	50.7	128	780	824
23	.24	.....	.31	129	48.3	.27	113	48.0	115	.....	712
30	.33	44.8	.43	134	46.7	.36	109	45.5	120	.....	555
Nov. 6	.90	46.7	1.23	137	46.7	.98	109	49.0	126	.....	700
Totals and percentages based upon these totals[d]	40.34	.....	50.63	125.5	.....	43.92	108.9	.....	.....	.....	.....
Mean weekly percentages	.....	.....	.....	126.0	.....	.....	108.1	.....	116.1	.....	.....

[a] Diameter, 12 feet, and 3 feet deep, set in ground 2.75 feet.
[b] 3 feet square by 3 feet deep, set in ground 2.75 feet.
[c] United States Geological Survey standard floating pan, on near-by lake, 3 feet square by 1.5 feet deep.
[d] Total evaporation from tank 3 expressed as a percentage of the total from No. 9 $= \frac{50.63}{43.92} \times 100 = 115.3$.

Figure 6 shows the relative temperatures of air (in instrument shelter), surface of water in tank 3, surface of water in tank 7, surface of water in tank 9, and the lake. Observations were taken both of the water in the tank at the lake and the lake water itself. The means were invariably the same, but occasionally the tank water would become 1 degree colder at night and 1 degree warmer during the day. No greater difference than 1 degree occurred. The difference is evidently due to influence of the radiation and concentration of the metal float tubes and the metal of the tank itself. The effect of heat storage is shown by the mean temperature curve; also the greater influence of the warm days over the cool

nights. Tank 3 has the low mean temperature; tank 7 comes between No. 3 and the lake, which is high. Figure 5 shows the influence of heat upon evaporation pans 2 feet in diameter under exactly the same conditions otherwise. There is no reason to believe that this relation would not extend to surfaces of larger water bodies of the same type. The curve would indicate that an increase of one degree mean temperature, all other conditions being the same, would increase the evaporation approximately 5 per cent at Denver for the season under consideration. The mean temperature of the lake is approximately 1 degree higher than

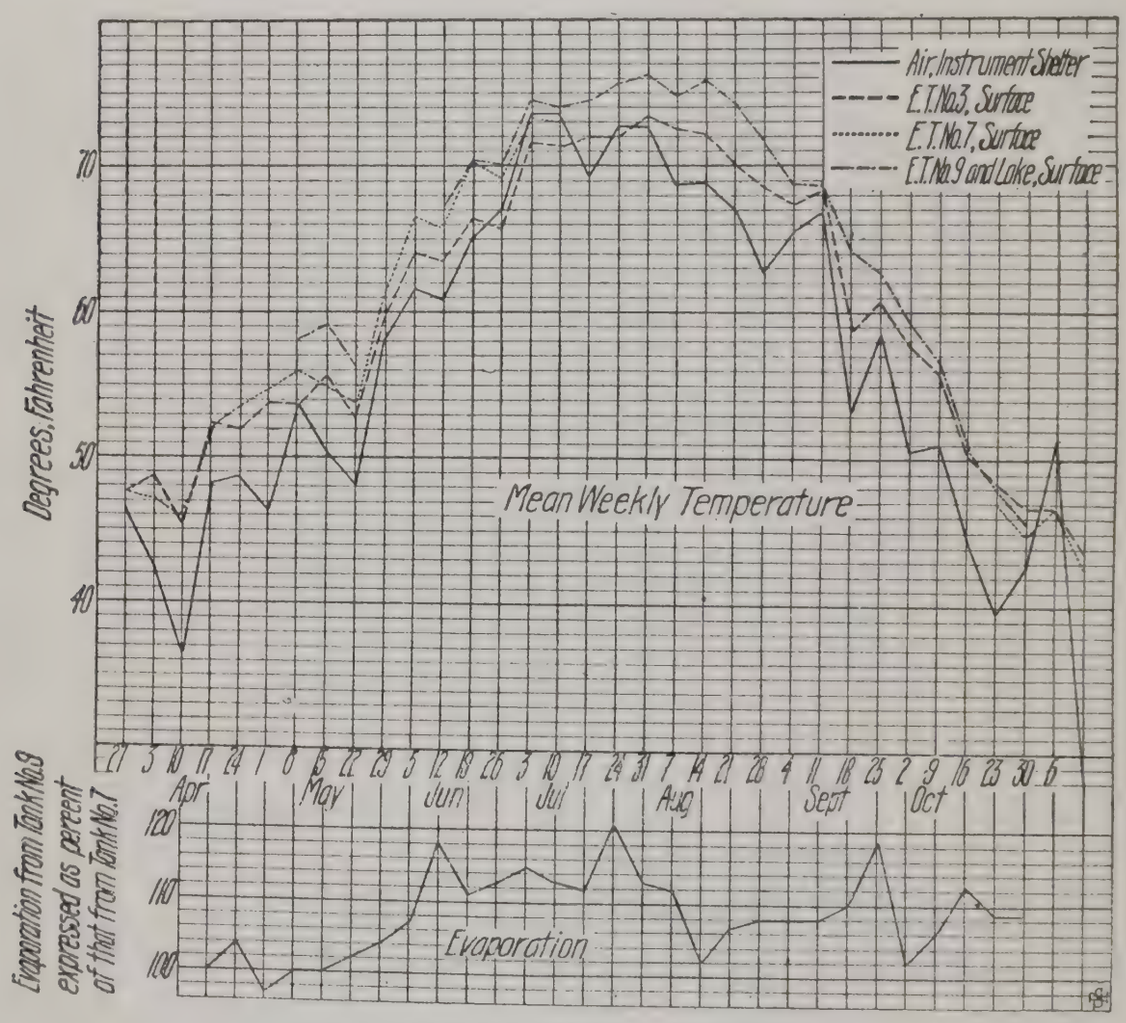

FIG. 6.—Relation of water and air temperatures.

that of tank 7. From that cause the lake evaporation would be then approximately 5 per cent more than that of tank 7. However, there is the ratio of perimeter to area, which would tend to make the lake evaporation less. The vapor-blanket effect mentioned previously would also lessen the lake evaporation in comparison with that from a land pan. The wind movement was practically the same at the lake as at the laboratory. A comparison between the 3-foot square tank at the laboratory and the floating tank would tend to strengthen the vapor-blanket theory. The mean temperature of the floating tank is higher, its wetted metal perimeter the same, yet its evaporation is less.

A careful consideration of all factors mentioned, and the curve (fig. 4) which is approaching the horizontal for the large areas, leads the writer to present the following conclusions:

(*a*) Evaporation figures from tanks 2 feet or greater in depth, preferably circular, set in the ground so that but a narrow metal rim not over 3 inches wide projects above the ground and in which water is kept approximately at the ground level, are most applicable for extension to large open-water surfaces.

(*b*) Data on such tanks may be quite safely extended to large open-water surfaces under exactly the same conditions of wind, air temperature, and relative humidity by multiplying the evaporation depth from a—

2-foot tank by 0.77	9-foot tank by 0.98
4-foot tank by 0.84	12-foot tank by 0.99
6-foot tank by 0.90	

Factors for depths from other tanks used have been found:

3 by 3 by 3 feet, sitting 2.75 feet in ground (Fort Collins type)	0.80
United States Geological Survey floating standard, 3 by 3 by 1.5 feet	.91
United States Weather Bureau for class A station, 4 feet in diameter, 10 inches deep, above ground	.66

These figures are not in agreement except in parts with those derived from previous work (8). However, it is quite certain that no previous investigation has gone into the problem in the manner of the one under discussion. The agreement between the results from a floating pan and a land pan of the same size is quite good; however, in many cases the description of the land pan does not state whether it was above the ground or set in the earth. It is quite probable that earlier figures obtained from the floating pan have been reduced too much in applying them to the reservoir itself. The tendency in comparing various records for floating and land pans has been to disregard the size of these pans. There are no data to show that the ratio existing between the figures from 3-foot land and floating pans would be the same as that from 6-foot land and floating pans. On the contrary, the great difference between the evaporation from land pans of 3 and 6 feet tends to show that the land-floating evaporation ratio is different for each size of pan.

METEOROLOGICAL OBSERVATIONS TAKEN IN CONNECTION WITH EVAPORATION INVESTIGATIONS IN GENERAL

In the course of the study the writer has, up to the present, referred to records in the original publications if possible, of evaporation measurements at 84 points in North America. It is the purpose to compile these in one table and present them to the public in a concise form if they can be correlated. In only a few instances have the figures been obtained

for purely scientific investigation; in most cases they were secured by engineers for immediate use in the study of a water supply and not under standard conditions, because there have been no standards. It is not strange that under these conditions the meteorological records are lacking. These evaporation depths undoubtedly served their purpose to the extent at least of satisfying the investigator. For the 84 stations, 31 have accompanying temperature figures, 9 relative humidity percentages, and 7 the wind movement. As they stand the records can be applied only under great disadvantage to other work, even in the same section. In many cases Weather Bureau records will supply part of the missing data which should accompany the evaporation figures proper, but not as satisfactorily as records taken at the evaporation station. It is obvious that Weather Bureau data, taken in a city, the station located on a roof, represent conditions which may differ greatly from those at a reservoir on which is floating an evaporation pan, though this reservoir may be but a few miles from the city station.

Factors which are at present believed to be the principal ones controlling evaporation are outlined. The effects of sunshine and radiation as measured by instruments for that purpose are understood even less than those of the so-called principal factors. There is, however, no proof that they are negligible, and a record of these may add to the value of future evaporation research.

TEMPERATURE

If water temperatures taken at the surface were available to accompany all evaporation measurements made, they would be of value. Evaporation research has proved that approximate calculation of amounts could be made from water temperatures alone. However, these data are to be had in connection with evaporation records in but few cases, and for estimating losses for districts where previous evaporation records have not been made water temperatures are never available. The increased value of the records justifies water-temperature measurements. Water temperatures are dependent upon air temperatures.

The long establishment and very complete records of the Weather Bureau make it possible to secure data on air temperature for all parts of the country, taken under standard and somewhat similar conditions (27). The advantage of a method of basing evaporation estimates upon these records is obvious. The publications of that Bureau present daily records arranged in periods of one calendar month. Mean temperatures are essential, and from the records means may be found for periods of any length. A month is too long, since there may be such variations during the period that the mean does not correctly define the conditions in their application to evaporation. One day is too short, since water-temperature variations lag behind those of air, and their effect may be shown several hours later on the evaporation record. Periods

of one week have been used in this investigation and are recommended. This statement is made with reference to the practical application of temperature data to evaporation estimates. For the much-sought evaporation law it is quite probable that the unit of time will be shorter. Means will probably not be used in the final solution of the problem, and the time interval will be reduced to minutes. However, then to apply this to field conditions and make use of the existing data the unit will be lengthened and the exact evaporation law (when that is finally discovered) may have to be approximated for practical application.

Registering maximum and minimum thermometer records are used in arriving at the weekly means. Their agreement with the mean as found by the use of the thermograph proves their reliability. A thermograph record sheet for one week is shown as figure 7. From it the maximum and minimum temperatures for each day have been taken and their means found. Table XIII, showing these figures and daily means found by integrating the thermograph curves, gives from the curve a weekly mean of 51° F.; by the other method 53°.

TABLE XIII.—*Analysis of temperature from thermograph record for the week of September 11–18, 1916.* (*See fig. 7*)

Day of week.	Temperature (°F.).			Mean obtained by planimeter from graph for 24 hours ending 7.00 a. m.
	Maximum for 24 hours ending 7.00 a. m.	Minimum for 24 hours ending 7.00 a. m.	Mean maximum + minimum ÷ 2 for 24 hours ending 7.00 a. m.	
Tuesday	50	39	44	43
Wednesday	72	44	58	57
Thursday	80	40	60	58
Friday	55	32	44	42
Saturday	68	39	54	50
Sunday	70	40	55	51
Monday	73	38	56	56
Mean for the week	.....	.....	53	51

WIND MOVEMENT

Practically all of the proposed evaporation formulas have included the wind factor. It is evident, that to be applicable directly, the wind movement figures used should represent that movement quite close to the water surface. The Weather Bureau records represent standard conditions as near as possible, but with the anemometer 18 to 30 feet above the building on which it is located, and that building of no standard height (26). Ordinarily these records will have to be reduced to apply them directly to evaporation estimation. At the Denver laboratory the records show for the period April 17 to October 31 an average velocity

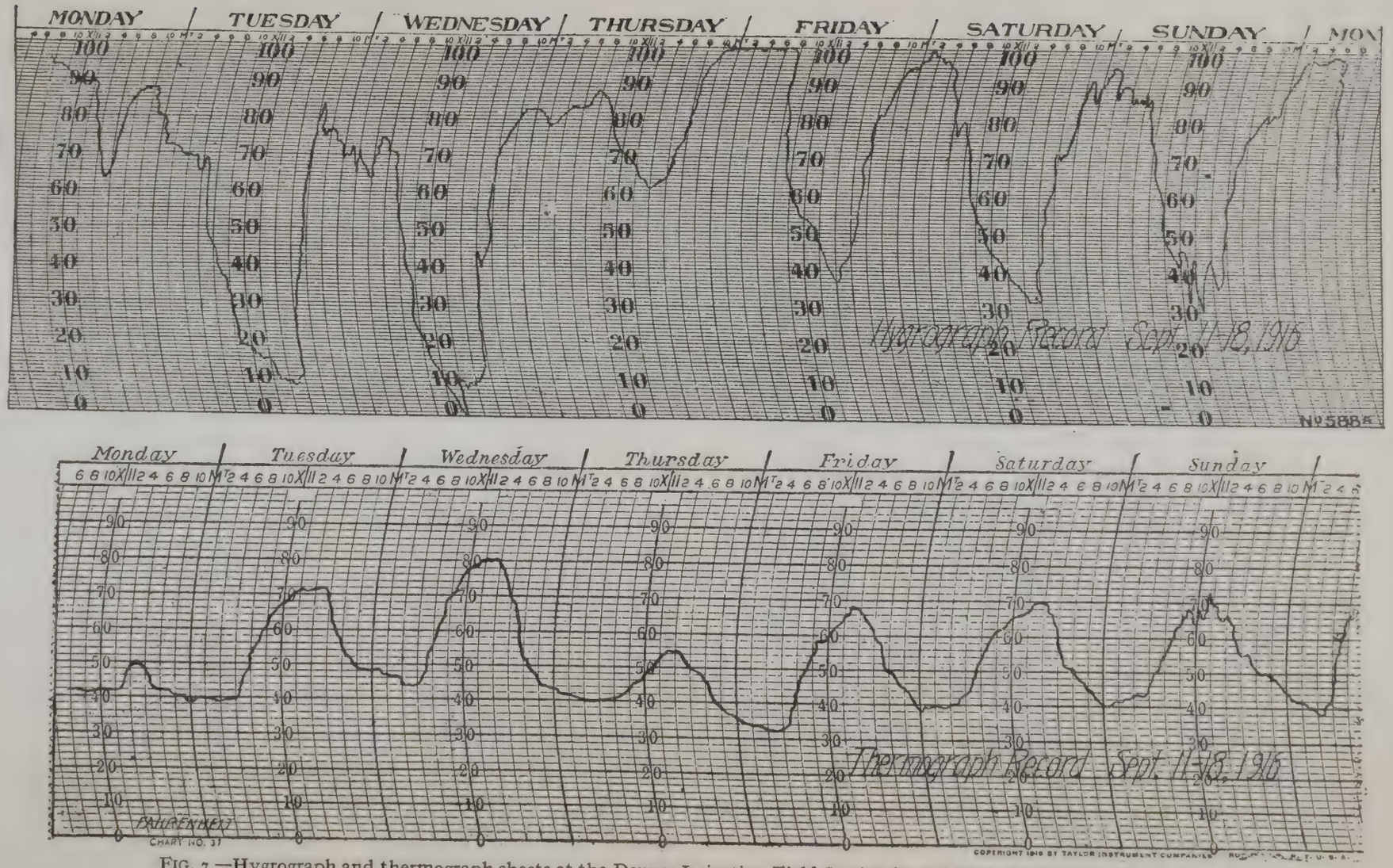

FIG. 7.—Hygrograph and thermograph sheets at the Denver Irrigation Field Station for the week of September 11 to 18, 1916.

of 7.4 miles per hour for anemometer 1, 14 feet above the ground, and 5.3 miles per hour for anemometer 3, 2 feet above the ground. The increase is 39 per cent. An investigation of the variation of wind velocity at different heights in connection with the Salton Sea investigation gave justification for the use of a formula which indicated that the velocity at a point, which from the beginning of the discussion referred to must have been 45 feet above the ground, was 141 per cent of the velocity at the bottom of the tower. This tower was fully exposed and free from interference to wind movement. The variation from the bottom of the tower to the top is shown as a straight line for all velocities (2, p. 30–31). Records giving a comparison between wind movements at the top of the Eiffel Tower, 984 feet, and the housetop level of Paris, probably less than 50 feet, indicate that the tower velocity is about four times that at the housetop level (14, p. 373).

Each evaporation observation station should have its own anemometer. Weather Bureau records of wind movement taken in connection with future evaporation measurements will probably give figures for the water surface, or approximately so (17).

RELATIVE HUMIDITY

An indication of the quantity of moisture mixed with the air is given by the relative humidity percentage. This, determined from the temperature of evaporation, should, in connection with other factors, be an index of evaporation depths from water surfaces. The term and its value are somewhat indefinite, being "relative." Taken in connection with the corresponding air temperature, the vapor pressure is obtained, which factor has been used in nearly all of the theoretical evaporation formulas proposed. Relative humidity figures or data form which to get these should accompany water surface evaporation studies. In many cases they do, usually taken, however, but once or twice a day. The use of the wet and dry bulb thermometer is doubtless the best method; however, a continuous record, by far the most valuable, is next to impossible by its use. The two readings a day method, however, gives an approximation to the integrated curve of the hygrograph, if the means are considered for a period of some length. As an illustration of this, a reproduction of the humidity record for one week is shown in figure 7 and the data are given in Table XIV.

The weekly mean from all 7 o'clock readings from this is 70 per cent. The integrated mean is 65 per cent. If but one reading a day is given, as is sometimes done, the variation is still greater, since the range during the day, particularly in this climate, is great. The hygrograph when properly adjusted and checked frequently with the psychrometer gives the most satisfactory record for evaporation use.

TABLE XIV.—*Analysis of relative humidity from hygrograph record for the week of September 11 to 18, 1916. (See fig. 7)*

Day.	Relative humidity (per cent).						
	Noon reading.	7 a. m. reading.	7 p. m. reading.	Mean from 7 o'clock readings.		Mean obtained by planimeter from graph.	
				Day.	Night.	Day.	Night.
Monday	89	89	82	86	66	80	76
Tuesday	17	50	36	43	52	21	68
Wednesday	10	67	43	55	64	21	78
Thursday	71	85	73	79	86	69	95
Friday	54	100	58	79	68	56	87
Saturday	45	79	58	68	70	45	82
Sunday	45	81	70	76	75	47	87
Monday	.....	80	.....	.....	.....	.....	.....
Weekly mean from noon readings	47	.....	.....	.....		.....	
Weekly mean from 7 a. m. readings	.....	79	.....	.....		.....	
Weekly mean from 7 p. m. readings	.....	.....	60	.....		.....	
Weekly mean from all 7 o'clock readings	.....	.....	.....	70		.....	
Weekly mean from the graph	.....	.....	.....	.....		65	

BAROMETRIC PRESSURE

Theoretically variations in atmospheric pressure as shown by the barometer should have an effect upon the rate of evaporation from water surfaces. With the variation of 1 inch at the Denver laboratory this effect could not be determined or even detected. It is quite probable that within the limits of variation of barometric pressure at any one station the effect of the variation is not material at the temperatures of the water bodies under investigation.

PART II.—EVAPORATION FROM THE SURFACES OF STREAM-BED MATERIALS

In many places the North Platte River, the South Platte River, the Rio Grande, and other western streams the water of which is used for irrigation have smooth and nearly level beds from ½ to 1 mile and over in width. Part of the year these may be covered with water; at other times the water table is below the surface of the sand. When they are covered, there is a loss going on from evaporation, but usually these floods occur at a season when evaporation rates are relatively low. Much of the time during the months when evaporation rates from a water surface are high the water table in the rivers is below the top of the sand. That there is a loss from this sand surface has not been questioned, but there have been no figures from which to estimate this loss.

If it is assumed that the bed of a stream is ½ mile wide, in a 2-mile length there is a square mile of exposed sand. If it is assumed that this is a water surface from which the evaporation is 40 inches a year, the loss for that year would amount to over 2,100 acre-feet. Even if the evaporation is only a small part of that, the loss is extensive over a 200 or 300 mile length of stream bed.

This evaporation can not be prevented, but it can be estimated quite accurately, provided basic data are available. These estimates are necessary in order to answer fairly questions pertaining to equitable division of water. So far as can be learned, only one previous investigation has been carried on the results of which may be applied to this problem.[1]

A study of this loss was made at the Denver Laboratory during the season 1916. In general, the method was the following: Typical stream-bed materials were secured; these were placed in water-tight tanks; the water table was held at certain fixed levels; the loss by evaporation was measured; the final figures for this loss are given as a percentage of the loss from a water surface.

RIVER-BED MATERIALS USED

At the beginning of the work samples of river-bed materials were secured from the principal streams. The specifications for the collection of these called for

> at least two samples, each of which will represent an average type of river bed material. These samples should be taken in a vertical section extending from the surface to the depth of 24 inches.

Each lot consisted of 20 pounds. Materials from 27 points, covering 16 different streams, were obtained. These are given in Table XV, with their numbers, location on the river, and the collector's name. This number will be used throughout the discussion.

[1] DIESEM, H. C. PRELIMINARY REPORT, PLATTE VALLEY INVESTIGATION. Unpublished.

TABLE XV.—*List of river-bed materials analyzed*

[Numbers refer to those given on diagrams and in other tables]

Sample No.	River and location.	Collector of sample.
1	South Platte, Denver, Colo., intersection of river and Yale Street, screened through ¼-inch revolving.	Commercial.
2	North Platte, south of Mitchell, Nebr.	H. C. Diesem.
3	Cache la Poudre, Colo., 300 feet W. of E. line of sec. 3, T. 7 N., R. 69 W., on an island.	R. G. Hemphill.
4	Cache la Poudre, just below Bellvue Bridge, sec. 30, T. 8 N., R. 69 W.	Do.
5	Cache la Poudre, Windsor, Colo.	Carl Rohwer.
6	Cache la Poudre, Greeley, Colo.	Do.
7	South Platte, 1 mile above mouth of Cache la Poudre.	Do.
8	South Platte, at Evans, Colo.	Do.
9	South Platte, at river bridge south of North Platte, Nebr.	H. C. Diesem.
10	Cherry Creek, intersection with Steele Street, Denver.	Commercial.
11	Arkansas, at Avondale, Colo.	J. M. Murtha.
12	Rio Grande, 1½ miles west of Mesilla, N. Mex.	D. W. Bloodgood.
13	Salt, near Mesa, Ariz.	P. E. Fuller.
14	Colorado, Imperial Canal intake.	F. J. Vielmeyer.
15	Santa Ana, Riverside, Cal., above West Riverside Bridge. A large part of this came out of Lytle Cañon, winter 1915–16.	W. W. McLaughlin.
16	Santa Ana, southeast of Fullerton, Cal.	Do.
17	San Joaquin, Cal.	R. D. Robertson.
18	Sacramento, Princeton, Cal.	Charles Kaupke.
19	Sacramento, Calusa, Calusa County, Cal.	Do.
20	Feather, N. line sec. 4, T. 18 N., R. 3 E., Mount Diablo base and meridian, Cal.	H. S. Patton.
21	Feather, S. line sec. 9, T. 16 N., R. 3 E., Mount Diablo base and meridian, Cal.	Do.
22	Columbia, 1 mile below mouth of Snake, near Burbank, Wash.	E. M. Chandler.
23	Umatilla, ¼ mile below Maxwell diversion dam, 9 miles from mouth of river, Oreg.	P. S. Jones.
24	Umatilla, ¾ mile above Maxwell diversion dam, 10 miles from mouth of river, Oreg.	Do.
25	Yakima, near Grandview, Wash.	J. G. Heinz.
26	Yakima, near Toppenish, Wash.	Do.
27	Sevier, Utah.	L. M. Winsor.

A mechanical analysis of each sand was made. The screens used were standard 8-inch diameter, of the following sizes, or mesh per inch: 1, 4, 12, 16, 20, 30, 40, 50, 60, 80, and 100. At least three 1,000-gm. runs were made on each sample, and in case of any practical variation the entire 20-pound lot was screened. The screens were handled by means of a mechanical shaker (23), and the percentage of voids was obtained by the usual water method. Table XVI gives the complete data of the analysis. The graphical representation of this is shown in figures 8 to 10.

TABLE XVI.—*Results of mechanical analyses of river-bed materials.* (*See fig. 8–10*)

[Numbers refer to those given in the list of materials]

PERCENTAGE RETAINED ON SCREEN

Screen No.	Material No.																									
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
1	0	0	5.8	0	22.5	29.8	2.5	2.4	0	0	0	0	25.1	Seeds and sticks up to screen 50	0	0	0	16.6	0	68.0	0	26.6	32.1	34.6	0	45.4	0
4	.4	0	6.0	31.1	18.4	19.0	17.7	24.8	0	0	0	0	15.4		0	7.0	0	39.3	0	19.5	0	35.1	36.4	41.4	0	30.3	0
12	37.5	16.1	3.5	31.6	6.9	12.9	21.3	26.9	32.4	13.0	[a]2.2	0	9.3		0	9.2	0	14.9	0	4.6	0	7.5	10.7	6.3	.7	5.8	.5
16	12.7	8.4	.7	4.0	3.1	5.6	6.1	8.3	11.0	6.8	1.0	0	5.0		2.8	5.4	0	3.3	0	1.1	0	.3	2.4	1.2	.8	.9	1.0
20	8.9	7.2	.7	1.9	3.4	4.3	5.1	.7	9.8	6.9	4.2	0	5.4		1.8	5.6	.8	2.6	0	.9	0	.1	2.2	.9	1.2	.6	2.1
30	17.2	21.0	5.0	3.3	13.0	10.1	14.8	12.8	18.8	18.0	21.9	.1	15.5		10.6	18.6	.5	5.8	.2	1.7	.4	.2	4.1	2.3	9.4	1.5	18.2
40	10.2	17.7	11.1	5.2	12.4	5.6	15.6	8.7	13.2	17.0	24.3	.7	11.5		17.8	18.2	.7	3.9	.7	.9	1.0	1.2	2.9	2.0	35.0	2.2	32.3
50	5.3	9.9	10.7	5.9	6.4	3.1	9.3	4.3	6.6	13.0	13.6	5.5	5.6	.1	14.2	11.6	1.5	1.7	1.4	.6	2.0	4.2	1.9	2.0	25.0	2.1	19.6
60	2.9	7.0	11.7	5.9	4.0	2.3	4.3	2.7	4.1	9.6	9.1	16.5	3.0	.4	11.9	8.5	3.5	1.1	5.2	.5	5.2	6.0	2.0	2.0	16.7	2.2	13.7
80	2.2	5.8	14.1	4.8	2.5	1.4	2.0	1.8	2.5	7.5	6.7	35.2	1.5	1.5	12.0	6.4	13.5	1.1	34.8	.5	21.8	6.1	1.5	1.6	4.4	2.1	7.8
100	1.4	3.7	10.7	3.3	1.8	1.6	.8	.9	1.4	4.0	5.7	9.0	1.4	6.9	11.6	4.3	36.0	1.3	30.8	.4	47.8	5.6	1.1	1.9	3.0	2.1	3.3
Passing 100	1.3	3.2	18.9	2.7	5.4	3.5	.5	.7	.2	3.7	13.1	33.0	1.1	90.5	17.3	4.9	43.7	7.1	26.7	2.2	50.7	5.6	2.6	3.8	3.9	4.7	1.2

PERCENTAGE OF VOIDS

Composite material	43.7	35.3	39.2	35.3	[b]37.7	[b]31.9	35.8	35.4	32.0	39.2	37.6	41.4	[b]35.5	43.1	38.4	39.0	.....	.....	49.1	31.2	49.2	[b]37.6	[b]27.5	[b]31.7	.....	.....	.....
Passing 20, retained on 30	45.1	42.8	48.6	47.1	46.2	44.0	43.5	45.4	44.0	48.5	45.4	.....	44.9	.....	47.1	44.8	.....	41.5	.....	44.3	.....	.....	45.3	43.8	.....	.....	.....
Passing 60, retained on 80	45.2	46.0	47.4	50.2	47.2	47.5	47.3	47.4	43.7	50.1	45.7	46.3	46.9	52.9	47.8	46.8	.....	49.4	52.2	46.6	49.2	47.9	48.1	47.9	.....	.....	.....

[a] Sticks. [b] The large amount of coarse material made a screening necessary before an analysis for voids. This analysis was made on all passing screen 4.

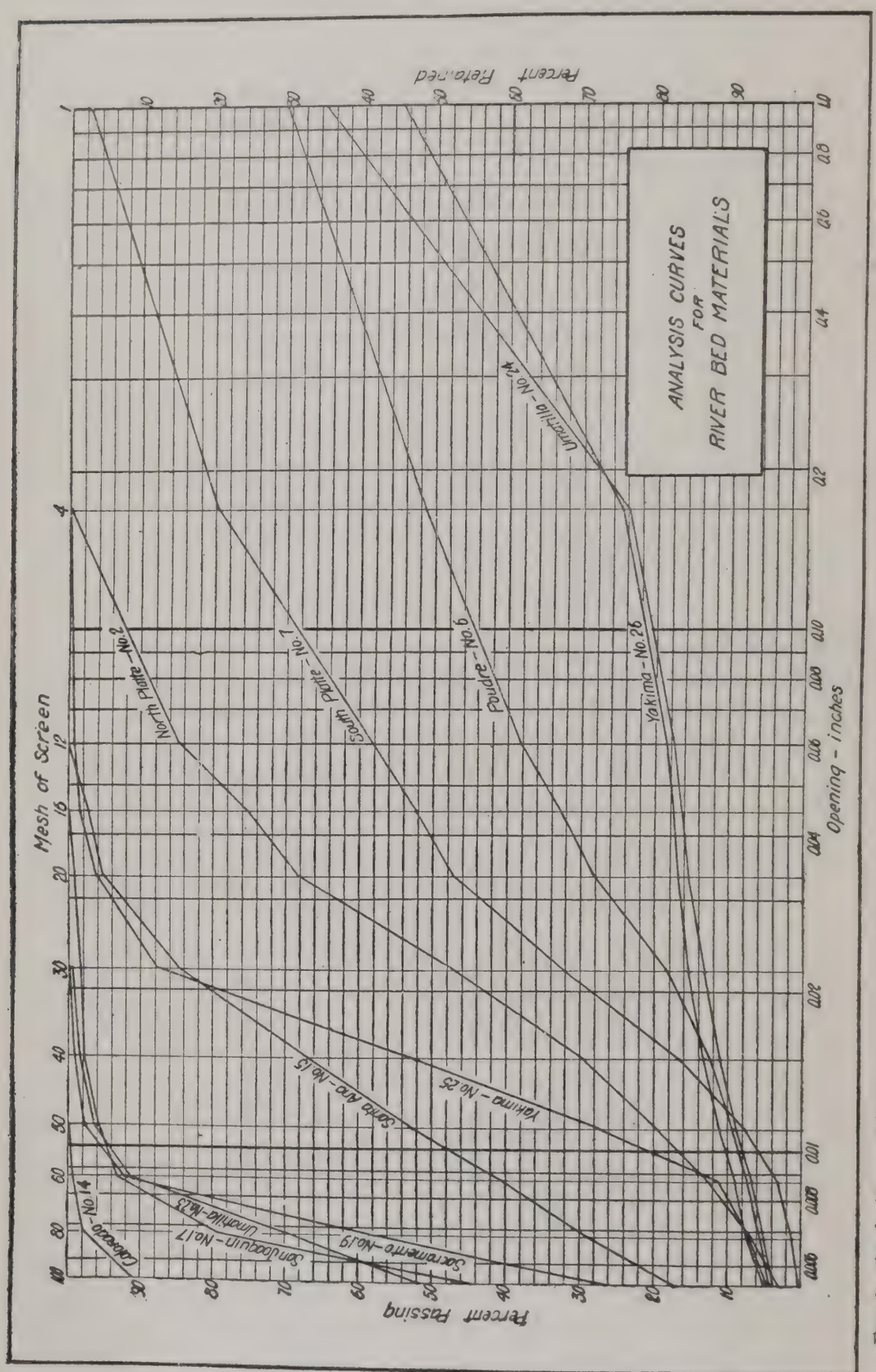

FIG. 8.—Analysis curves for river-bed materials from the Cache la Poudre, Colorado, North Platte, Sacramento, San Joaquin, Santa Ana, South Platte, Umatilla, and Yakima Rivers.

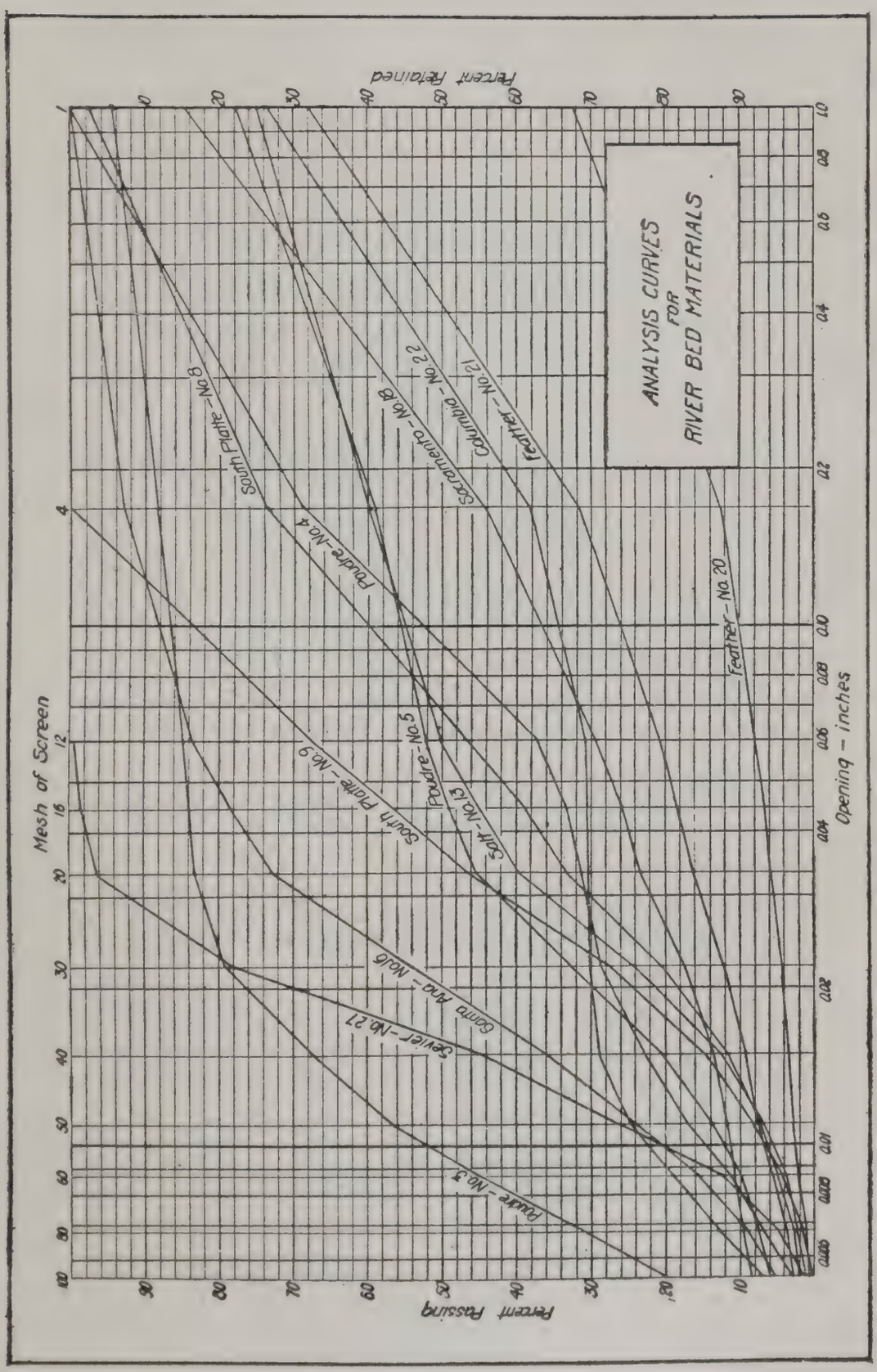

FIG. 9.—Analysis curves for river-bed materials from the Cache la Poudre, Columbia, Feather, Sacramento, Salt, Santa Ana, Sevier, and South Platte Rivers.

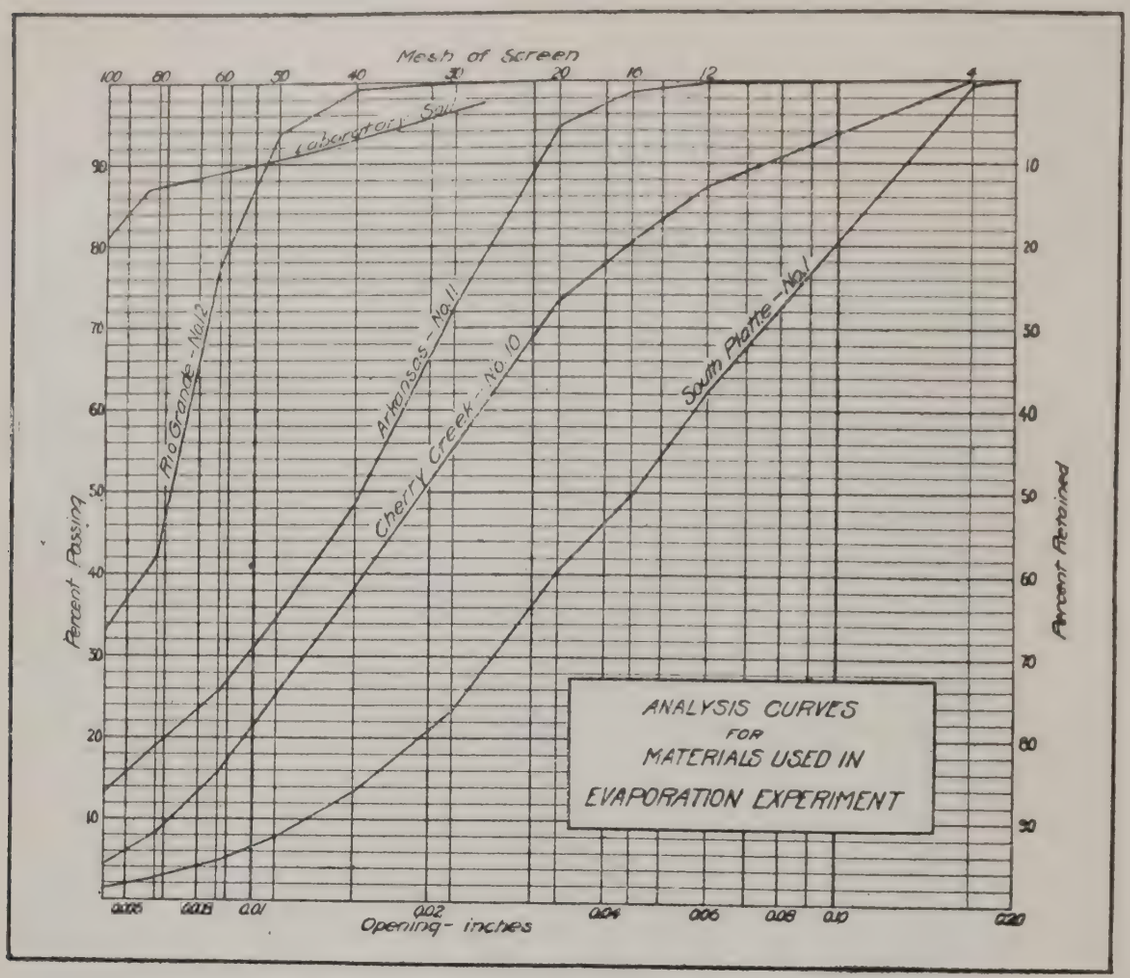

FIG. 10.—Analysis curves for materials used in evaporation experiment.

In this connection an analysis of the laboratory soil was made by the Bureau of Soils. The result of that analysis for the soil of the top 2 feet is given in Table XVII.

TABLE XVII.—*Mechanical analysis of the top 2 feet of the Irrigation Field Laboratory (Denver, Colo.) soil as made by the United States Bureau of Soils*

Depth	Organic matter.	Fine gravel (2–1 mm.).	Coarse sand (1–0.5 mm.).	Medium sand (0.5–0.25 mm.).	Fine sand (0.25–0.1 mm.).	Very fine sand (0.1–0.05 mm.).	Silt (0.05–0.005 mm.).	Clay (0.005–0.0 mm.).
Foot.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1	0	1.0	6.8	5.9	39.0	20.9	14.6	11.9
2	0	3.6	5.7	3.0	30.6	20.2	17.1	19.8
Average	0	2.3	6.2	4.5	34.8	20.5	15.8	15.8

The laboratory soil, while not a water-washed river-bed material, offered opportunity for work with a material of fine texture; and the results from its use are given in connection with those from the strictly river-bed sands.

With the facilities and funds available it was not possible to make a complete investigation of each individual sand from the standpoint of

evaporation loss. Nor is it thought that such an investigation would have been of greater value than the one carried out. Typical sands to be used in the study were selected, No. 10 and 11 having a mean analysis curve, No. 12 representing a fine material, and No. 1 a coarse sand. Then in addition laboratory soil was used, this being of a still finer texture than No. 12.

EQUIPMENT

All records from water-surface evaporation tanks were taken, and all meteorological observations were made in connection with water-surface evaporation. No special apparatus was required for that. The equipment for the sand work consisted mainly of the Fortier type of water-jacketed tank (10, 11) shown as *D*, figure 3. Plate 38, *A*, shows the installation of these. Net losses from evaporation were determined by weight, the tanks being lifted to the platform scales in the manner shown in Plate 38, *B*. This motor-driven hoist runs on wood rails; its capacity is 2,500 pounds. Since the water levels were below the surface, a well (tin pipe 1 inch in diameter) was placed in each tank and the top closed with a cork stopper (Pl. 38, *A*). A description of the tanks is given in Table XVIII.

TABLE XVIII.—*Description of tanks used*

Tank No.	Diameter.	Depth.	Filled with sand No.	Water table.
	Inches.	*Feet.*		
27–28....	23.5	4	10	6 inches above the sand surface.
29–30....	23.5	4	10	3 inches above the sand surface.
31–32....	23.5	4	10	Surface saturated.
33–34....	23.5	4	10	3 inches below the sand surface.
35–36....	23.5	4	10	6 inches below the sand surface.
37–38....	23.5	4	10	12 inches below the sand surface.
39–40....	23.5	4	10	24 inches below the sand surface.
41–42....	23.5	4	12	3 inches below the sand surface.
43–44....	23.5	4	12	12 inches below the sand surface.
45–46....	23.5	4	11	Do.
47–48....	30.0	3	11	3 inches below the sand surface.
49–50....	30.0	3	1	Do.
51–52....	30.0	3	1	12 inches below the sand surface.
53.....	30.0	3	10	3 inches below the sand surface.
54.....	30.0	3	10	12 inches below the sand surface.
55–56....	23.5	1	(a)	4 inches below the surface.
57–58....	23.5	2	(a)	16 inches below the surface.
59–60....	23.5	3	(a)	28 inches below the surface.
61–62....	23.5	4	(a)	40 inches below the surface.
63–64....	23.5	5	(a)	52 inches below the surface.
65–66....	23.5	6	(a)	64 inches below the surface.

[a] Labaratory soil.

There were available 15 hoods for use in time of storm. These were used on tanks for which the correction necessary for the addition of storm water was difficult to make.

OBSERVATIONS

After the tanks were installed and filled, water was applied until a stable level was reached according to the schedule in Table XVIII. Tanks were weighed about twice each week, the platform scales weighing to ¼ pound. Observations were kept on the water level, a morning record being made, starting at 8 o'clock, and in the afternoon beginning at 3.30, for the greater part of the season. During particularly dry periods observations were started at 6.30 a. m., 12.30 p. m., and at 6.30 p. m. At the time of each observation of the level, additions of water were made in even pounds to bring it to the fixed elevation. The depth measurements were made to ¼ inch with an ordinary rule. Some difficulty was experienced in keeping the tanks having the surface saturated in exactly the right condition. After a couple of weeks' use these were provided with individual supply reservoirs which allowed a small quantity of water to drip into the tank. Very close attention was required. The entire water losses from the tanks were determined by the weighings and from the amount added to keep the level at the desired point.

DETAILED DATA AND FINAL RESULTS

The 14 tanks containing Cherry Creek sand were installed with a view to using them as a so-called standard from which to determine the general form of the curve of evaporation loss at different water levels. Five points were possible: saturation, water at 3 inches, at 6 inches, at 12 inches, and at 2 feet. It happened that the final figures showed that 10½ inches had been used instead of 12 inches. With the use of laboratory soil, which is not truly the same type of material, six points were found with the equipment, water at 4, 16, 28, 38, 43, and 51 inches. Of the other types used it was thought that, since the form of the evaporation curve could be learned from the so-called standards, two depths would present the desired information. Accordingly, for sands 1, 11, and 12, two depths, 3 and 12 inches, were used.

The detailed results of all observations have been tabulated. Sand 10 is covered in Table XIX. During the period July 31 to October 16 the final figures show the following results: At saturation the evaporation was 77 per cent of that from evaporation tank 2, a water surface tank of the same area with water 2.75 feet deep; 3 inches below the sand surface, 69 per cent; 6 inches, 64.5 per cent; 10½ inches, 57.7 per cent; and at 24 inches, 11.3 per cent. Table XX shows the data from laboratory soil; Table XXI that from sand 12, Rio Grande; sand 11, Arkansas, is tabuated as Table XXII; and No. 1, Platte, is shown on Table XXIII.

TABLE XIX.—*Actual evaporation from Cherry Creek sand, No. 10, with water table at different depths below the material surface. All tanks 1.96 feet in diameter*

Period ending [a]—	Actual depth of water evaporated (inches).					
	Evaporation from water surface tank 2 (2 feet diameter and 3 feet deep).	Water table below the sand surface.				
		0 (saturation).	3 inches.	6 inches.	10½ inches.	24 inches.
Aug. 4	1.01	0.45	0.62	0.67	0.50	0.19
9	1.12	1.23	1.07	.80	.74	.15
12	.85	.75	.90	.80	.69	.18
15	.69	.40	.35	.32	.28	.04
17	.54	.68	.34	.29	.21	.04
29	3.54	2.51	2.54	2.42	2.22	.80
Sept. 12	4.44	3.14	2.71	2.62	2.47	.34
25	2.83	2.34	2.16	2.06	1.82	.25
29	.91	.46	.42	.40	.36	.12
Oct. 4	1.23	1.06	.69	.67	.63	.00
10	.99	.51	.54	.54	.50	.00
16	.88	1.04	.62	.62	.50	.16
Total	18.93	14.57	13.06	12.21	10.92	2.27
Percentage [b]	100.0	77.0	69.0	64.5	57.7	11.3

[a] The period began on July 31, 1916. [b] Water surface taken as 100 per cent.

TABLE XX.—*Actual evaporation from laboratory soil with water table at different depths below the soil surface. Experimental tanks 1.96 feet in diameter*

Period ending [a]—	Actual depth of water evaporated (inches).						
	Evaporation from water surface of tank 2 (2 feet in diameter).	Water table below the soil surface.					
		4 inches.	16 inches.	28 inches.	38 inches.	43 inches.	50½ inches.
Aug. 30	3.84	2.98	2.69	2.19	1.23	0.24	0.19
Sept. 15	4.77	4.37	4.09	3.12	1.98	.37	.32
25	2.10	1.81	1.67	1.44	.30	.16	.16
29	.91	1.04	.84	.69	.43	.11	.16
Oct. 4	1.23	1.14	.97	.58	.30	.10	.10
Total	12.85	11.34	10.26	8.02	4.24	.98	.93
Percentage [b]	100.0	88.2	79.8	62.4	33.0	7.63	7.24

[a] The period began on Aug. 17, 1916. [b] Water surface taken as 100 per cent.

TABLE XXI.—*Actual evaporation from Rio Grande material, No. 12, with water table at different depths below the surface. All tanks 1.96 feet in diameter*

Period ending [a]—	Actual depth of water evaporated (inches).		
	Evaporation from water surface of tank 2 (2 feet in diameter, 3 feet deep).	Water table below the surface.	
		3 inches.	12 inches.
Aug. 12	0.85	0.93	0.73
15	.69	.39	.48
17	.54	.49	.30
29	3.54	2.89	2.64
Sept. 12	4.44	3.36	3.05
25	2.83	2.16	2.13
29	.91	.78	.55
Oct. 4	1.23	.83	.83
10	.99	.51	.58
16	.88	.71	.43
Total	16.80	13.05	11.72
Percentage [b]	100.0	77.0	69.8

[a] The period began on Aug. 9, 1916. [b] Water surface taken as 100 per cent.

TABLE XXII.—*Actual evaporation from Arkansas material, No. 11, with water table at different depths below the surface*

Period ending [a]—	Actual evaporation depth (inches).		
	Evaporation from water surface of tank 2 (2 feet in diameter, 3 feet deep).	Water table below sand surface.	
		3 inches.	12 inches.
		Tank 2.50 feet diameter.	Tank 1.96 feet diameter.
Aug. 29	3.54	2.09	1.94
Sept. 12	4.44	2.88	2.61
25	2.83	2.25	2.05
29	.91	.49	.49
Oct. 4	1.23	.79	.70
10	.99	.55	.56
16	.88	.57	.43
Total	14.72	[b] 9.62	8.78
Percentage [c]	100.0	70.0	59.6

[a] The period began on Aug. 17, 1916.
[b] 10.32 equivalent for tank 1.96 feet in diameter. See Table XXIV giving ratio for this correction.
[c] Water surface taken as 100 per cent.

TABLE XXIII.—*Actual evaporation from South Platte graded river-bed material, 1, with water table at different depths below the surface. All tanks 2.5 feet in diameter*

Period ending [a]—	Actual depth of water evaporated (inches).		
	Evaporation from water surface of tank 2 (2 feet in diameter, 3 feet deep).	Water table below the surface.	
		3 inches.	12 inches.
Aug. 9	1.12	1.00	0.74
12	.85	.68	.45
15	.69	.39	.18
17	.54	.42	.29
29	3.54	1.75	1.01
Sept. 12	4.44	2.52	.49
25	2.73	1.90	.72
29	.91	.59	.14
Oct. 4	1.23	.63	.06
10	.99	.51	.00
16	.88	.63	.17
Total	17.92	11.02	4.25
Equivalent for tank 1.96 feet in diameter	.....	[b] 11.82	[b] 4.58
Percentage [c]	100.0	66.0	24.2

[a] The period began on Aug. 4, 1916.
[b] See Table XXIV for ratio for this correction.
[c] Water surface taken as 100 per cent.

From the list of tanks used it will be seen that No. 53 is a duplicate of Nos. 33 and 34, and that No. 54 duplicates Nos. 37 and 38, with the exception that 53 and 54 are 30 inches in diameter, while the others are 23½ inches. From work on evaporation from water surfaces, the difference in evaporation depths due to difference in size of the evaporation pan has been noted. Data were not at hand to show whether or not this relation would hold for the sand tanks. Table XXIV gives the results from the sand tanks of two diameters. The final figures indicate that for the period of the sand-tank work the evaopration from the surface of the sand from the smaller tank, approximately 2 feet in diameter, was about 7½ per cent greater than from the larger tank. This figure does not check that found for the water tanks, the corresponding difference there being 3½ per cent. The data do not indicate the cause of this difference, but the assumption is that it is due to a temperature effect. It is probable that the moist sand acts in a different capacity as a heat reservoir than does a tank of water.

TABLE XXIV.—*Relation between evaporation from sand tanks 1.96 feet in diameter and tanks 2.50 feet in diameter, with water table at 3 and 12 inches below the surface of the material*

Period ending [a]—	Actual evaporation (inches).			
	Water table 3 inches below surface.		Water table 12 inches below surface.	
	Tank 1.96 feet diameter.	Tank 2.5 feet diameter.	Tank 1.96 feet diameter.	Tank 2.5 feet diameter.
1916.				
Aug. 9	1.07	0.83	0.74	0.69
12	.90	.71	.69	.59
15	.35	.26	.28	.27
17	.34	.47	.21	.38
29	2.54	2.22	2.22	1.91
Sept. 12	2.71	2.52	2.47	2.01
25	2.16	2.02	1.82	1.81
29	.42	.55	.36	.46
Oct. 4	.69	.79	.63	.55
10	.64	.59	.50	.55
16	.62	.63	.50	.45
Total [b]	12.44	11.59	10.42	9.67

[a] The period began on Aug. 4, 1916.
[b] The ratio of evaporation from the tank 2.5 feet in diameter to that from the tank 1.90 feet in diameter is $\frac{12.44}{11.59}=1.073$ for a 3-inch depth of water table and for 12-inch depth of water table it is $\frac{10.42}{9.67}=1.078$.

The figures found for this comparison are used in the manner of correction factors in placing all evaporation results from sand upon the basis of a tank 2 feet in diameter. In the tables where this correction is made note is made of the change.

Figure 11 shows graphically the data given in Tables XIX to XXIII. It will be noted that the general slope of the lines is the same throughout. The form for the laboratory soil is similar to that of sand 10, and it is safe to assume that this form would be shown if more points were available for sand 1, the coarsest material used. The results seem consistent, with this exception: The loss from the saturated surface of No. 10 is 77 per cent of that from the water surface, while an extension of the curve for laboratory soil would tend to indicate that at saturation the loss from this would be much greater than 77 per cent. That evaporation from saturated surfaces, under apparently the same external conditions, should vary with the material of that surface seems questionable. The detailed results from sand 10 show also the individual figures to be inconsistent in connection with the saturated condition, being either greater or less than from the water surface, the cause of which is not evident. This is not true of the other figures of the series on this sand.

As was noted earlier, some difficulty was experienced in maintaining a uniform saturated condition. At no time was an automatic device used

to control the water level; by the tank arrangement it was necessary to entirely cut off the supply at night. During a part of the time a midnight observation was made, but not through all the season. Occasionally a greater depth than was required would be applied to the tanks, resulting in an excess of perhaps ⅛ to ¼ inch, never greater. The net result for the end of the season and for any day of the season was saturation. As all of the work done was performed with more care than is ordinarily used, the only explanation for the apparent discrepancy has been given.

In the final curves the results of this saturated condition are not incorporated. Examination of streams shows that the bed is very rarely in that condition. Water may be flowing in measurable depths, from a very small part of an inch up, or the sand will be moist, with the water table below the surface at varying depths. The saturated condition is rare in the extreme.

Tanks with water at depths of 3 and 6 inches were maintained throughout the run of the other tanks. The results are not given, since in weighing water was spilled at different times before the weight had been taken. Figures for losses from these tanks, when known to be correct, corresponded almost exactly with those for tanks in the series of varying depths, tanks 18 to 22, inclusive.

With the detailed data and curves of figure 11, together with the analysis curves for the river-bed material to work with, it was necessary to devise a means of showing the evaporation results based upon the sand-analysis figures in order to make the data of maximum value. There are two indices in common use representing the type or classification of a particular sand: Effective size and uniformity coefficient. The advantage of basing evaporation losses from wet sands upon one of these was obvious. A determination of both effective size and uniformity of coefficient was made for the materials used in the tanks. The effective size apparently offered the greatest possibilities. However, the water losses did not follow this consistently; uniformity coefficient was not at all applicable. The 60 per cent size, used in arriving at the uniformity coefficient from the effective size, was found to be much better. It is a term and classification in quite common use, defined as: That size of grain of material such that in mechanical screen analysis 40 per cent of the material by weight is larger and 60 per cent is smaller than that size, or based upon screen opening, that size of opening such that 60 per cent of the material passes and 40 per cent is retained.

When evaporation amounts were plotted as ordinates upon this 60 per cent size as abscissæ, fair curves resulted. To place the data in shape for use, Table XXV was prepared.

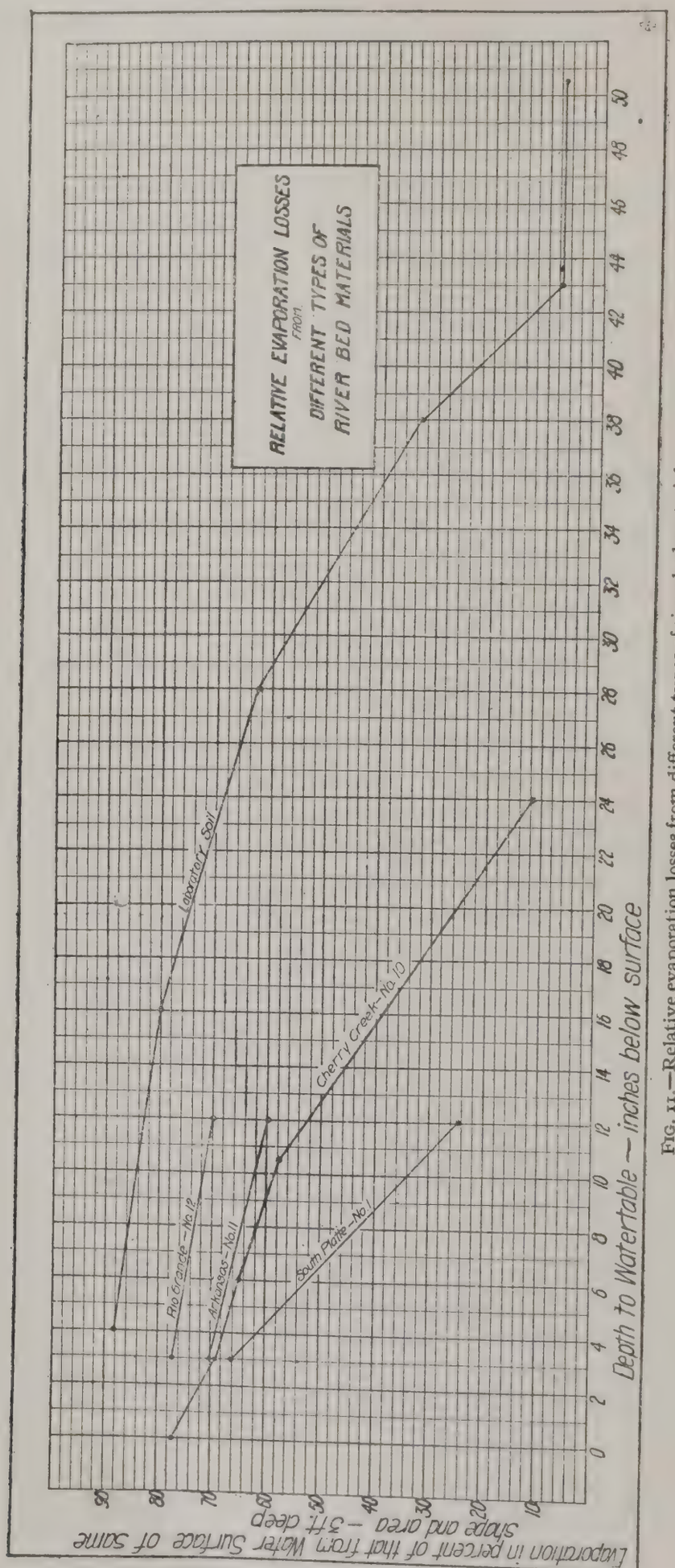
RELATIVE EVAPORATION LOSSES
FROM
DIFFERENT TYPES OF
RIVER BED MATERIALS
Laboratory Soil
Rio Grande – No. 12
Arkansas – No. 11
Cherry Creek – No. 10
South Platte – No. 1
Depth to Watertable — inches below surface
Evaporation in percent of that from Water Surface of same
shape and area – 3ft. deep

FIG. 11.—Relative evaporation losses from different types of river-bed materials.

TABLE XXV.—*Variation of evaporation loss from stream-bed materials, with size of sand grain—Water plane from 3 to 24 inches below the surface. (See fig. 11)*

Material used in experiment.	Effective size.	60 per cent size.	Uniformity coefficient.	Evaporation in percentage of that from free water surface of same shape and area, 3 feet deep, with a depth to water table of—				
				3 inches.	6 inches.	12 inches.	16 inches.	24 inches.
	Inch.	*Inch.*						
Laboratory soil	0.0001	0.003	3.00	[a]89	[a]86.6	[a]82.5	79.8	[a]68.0
Rio Grande 12	.0032	.0077	2.40	77	[a]74.5	69.8	.....	.....
Arkansas 11	.0049	.0180	3.68	70	[a]66.4	59.6	.....	.....
Cherry Creek 10	.0072	.0245	3.40	69	64.5	[a]53.0	[a]42.0	11.2
South Platte 1	.0152	.0570	3.75	66	[a]53.0	24.2	.....	.....

[a] Interpolated from figure 11. All other percentages are from Tables XIX to XXIII.

The evaporation percentages given include all the observed points shown in figure 11. Points interpolated from figure 11 are indicated. From this table figure 12 has been plotted. Observed figures are distinguished from the interpolated ones mentioned by the method of plotting.

Figure 13 shows the percentage of moisture in the top 4 inches of Laboratory soil with the water table at different depths. The upper curve, over the range of materials with 60 per cent size from 0.003 to 0.057 inch, indicates that with water 3 inches below the sand surface the loss by evaporation from this surface is from 89 to 66 per cent of that from a water surface of the same size and under the same external conditions. The graph shows these evaporation values for depths of water table from 3 to 24 inches, at 12 inches the range or loss being from 79 to 24 per cent, the greater loss in each case occurring from material of fine grain or texture.

TABLE XXVI.—*Factors for estimating evaporation losses from the surfaces of stream-bed materials*

[Multiply the evaporation from a water surface of the same size and similarly exposed by the factors given to get the evaporation from the sand surface]

Depth of water table below the surface.	Factor.				
	60 per cent size of the material (inches)—				
	0.01	0.02	0.03	0.04	0.05
Inches.	*Inch.*	*Inch.*	*Inch.*	*Inch.*	*Inch.*
3	0.74	0.69	0.69	0.68	0.67
6	.71	.66	.63	.59	.56
12	.67	.57	.49	.40	.30
16	.61	.47	.....	.....	.....
24	.44	.21	.....	.....	.....

One check upon this work has been found; in 1915 Diesem at North Platte found that the evaporation loss with water level 3 inches below the sand surface, from material from the South Platte River taken

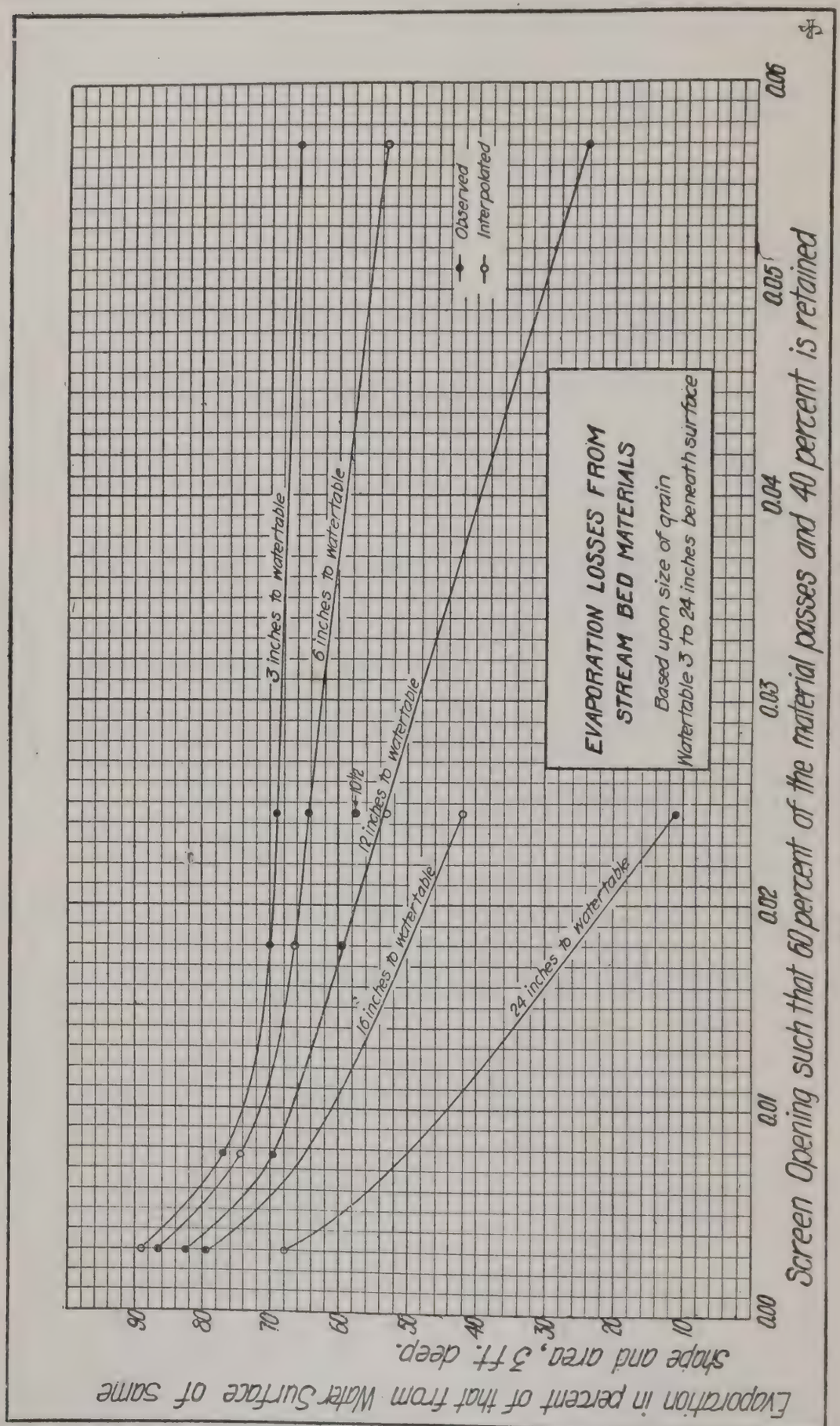

FIG. 12.—Evaporation losses from stream-bed materials.

from approximately the same point at which sample 9 was collected, was 61 per cent of that from a water surface. The 60 per cent size for that material, No. 9, as shown by figure 8, is 0.049 inch. From the upper curve of figure 12 the evaporation percentage corresponding to 0.049 inch is 67. Considering the fact that the North Platte work was done by means of tanks only 8 inches in diameter and the com-

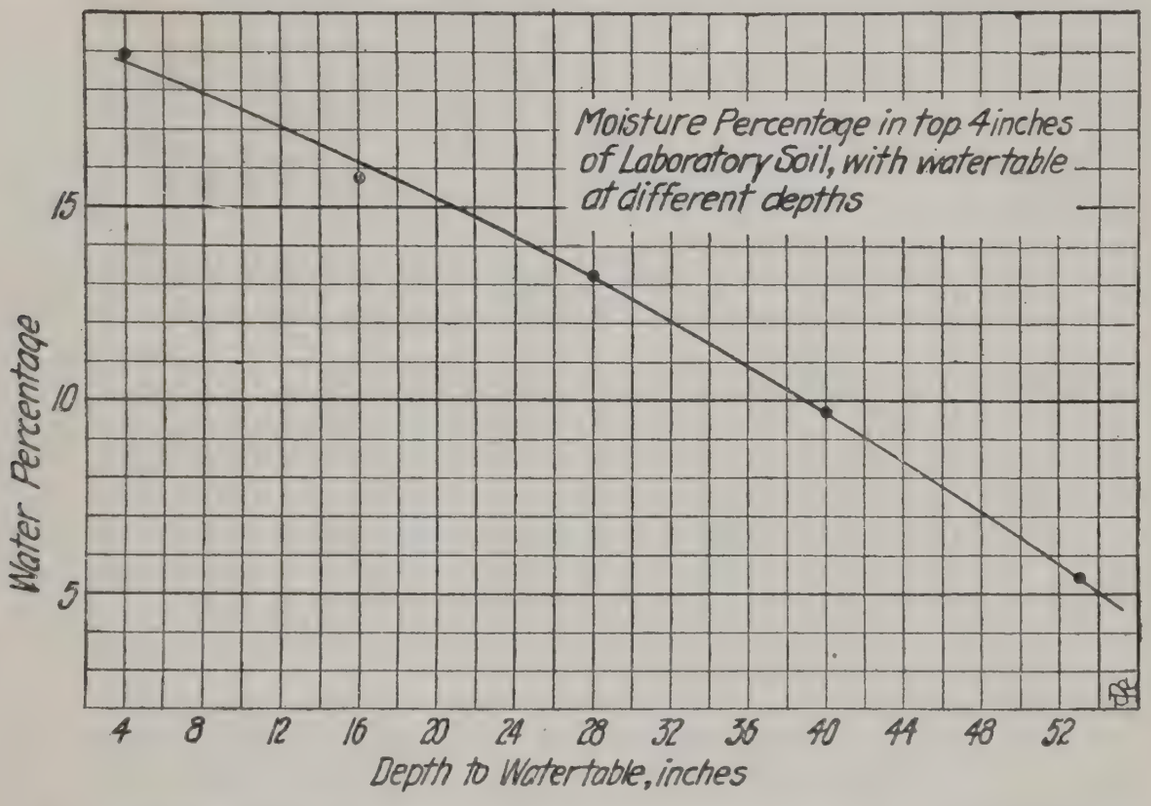

FIG. 13.—Moisture percentage in top 4 inches of Laboratory soil with water table at different depths.

parison made with a water surface tank in which the water was 2 inches deep, this check is considered close. Table XXVI will aid in the use of these data.

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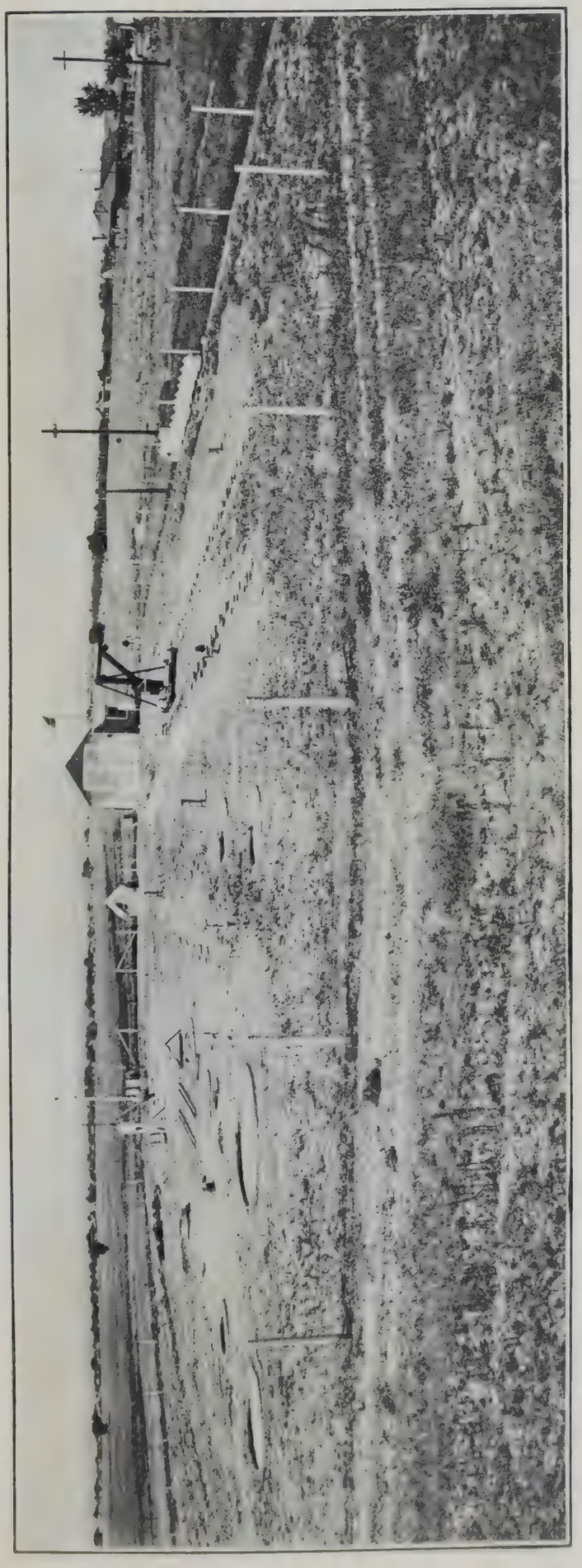
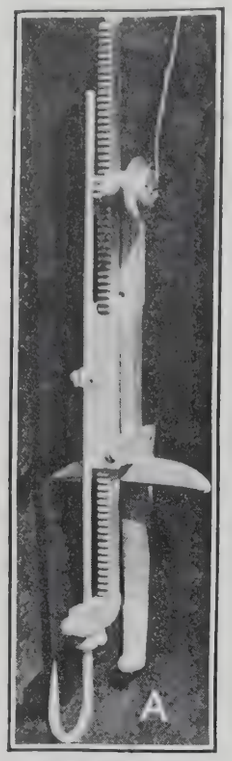
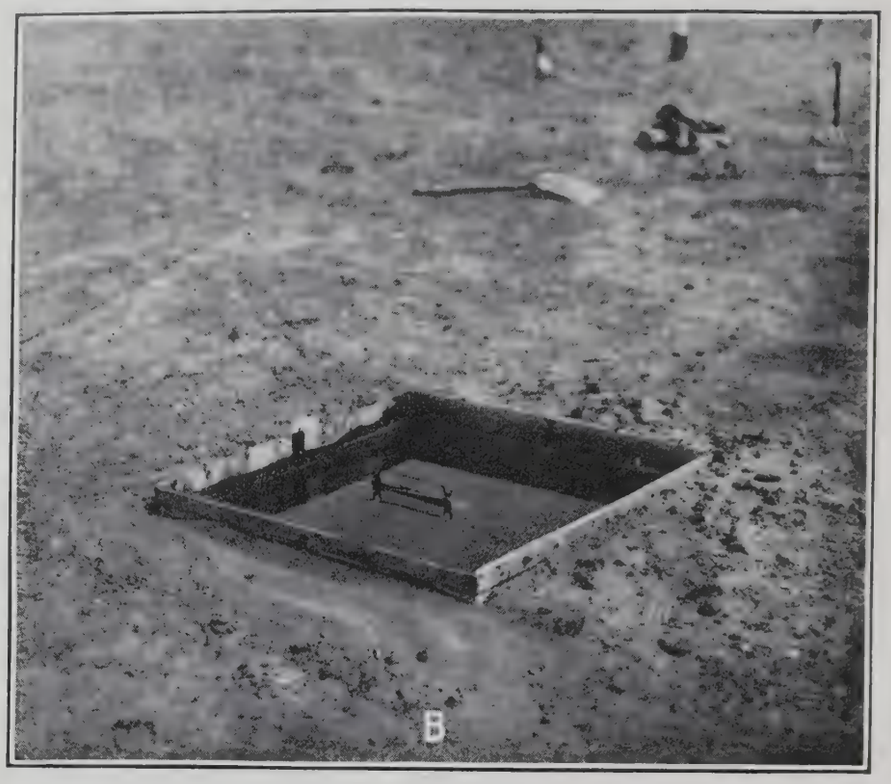
PLATE 33

General view of the irrigation field laboratory, Denver, Colo., looking west.




A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C

PLATE 34

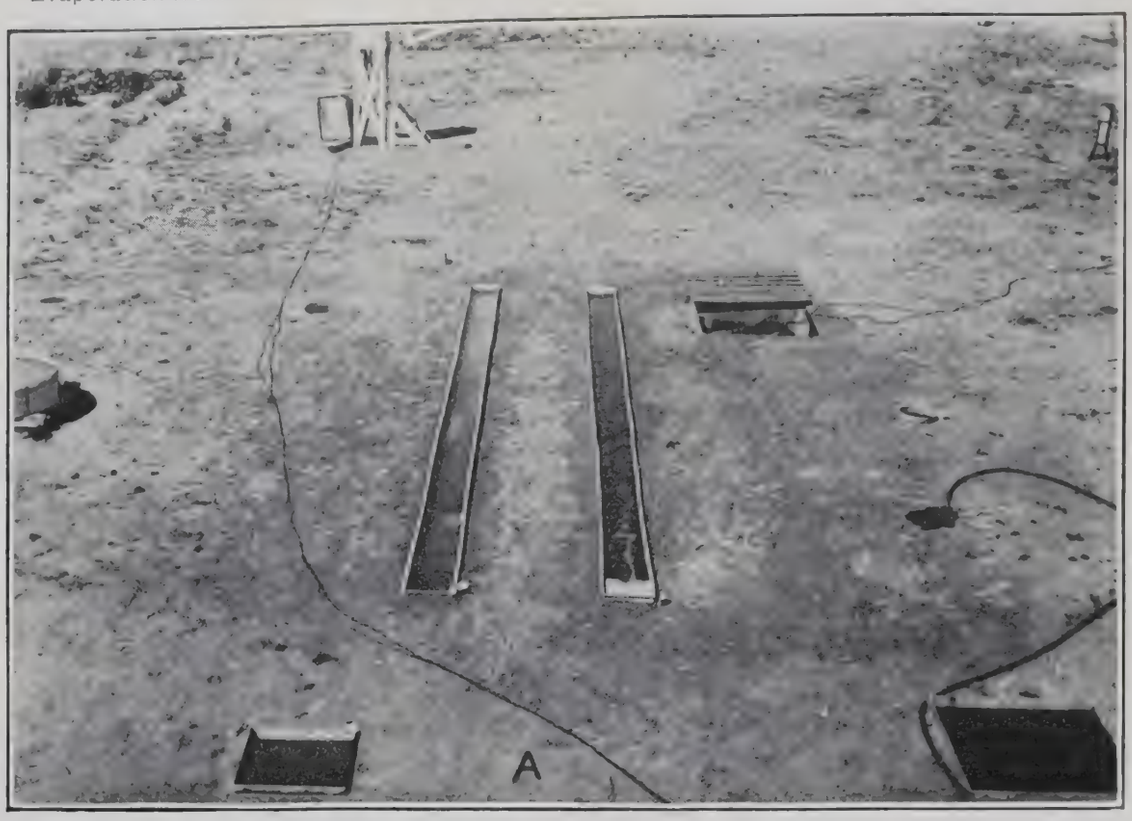
A.—Hoff hook gage for evaporation.
B.—Evaporation tank 3 after a sandstorm.
C.—Snow-covered evaporation tanks 4 and 7.

PLATE 35

A.—Three anemometers during a test run.
B.—Evaporation tank 7.

A

B


A

B

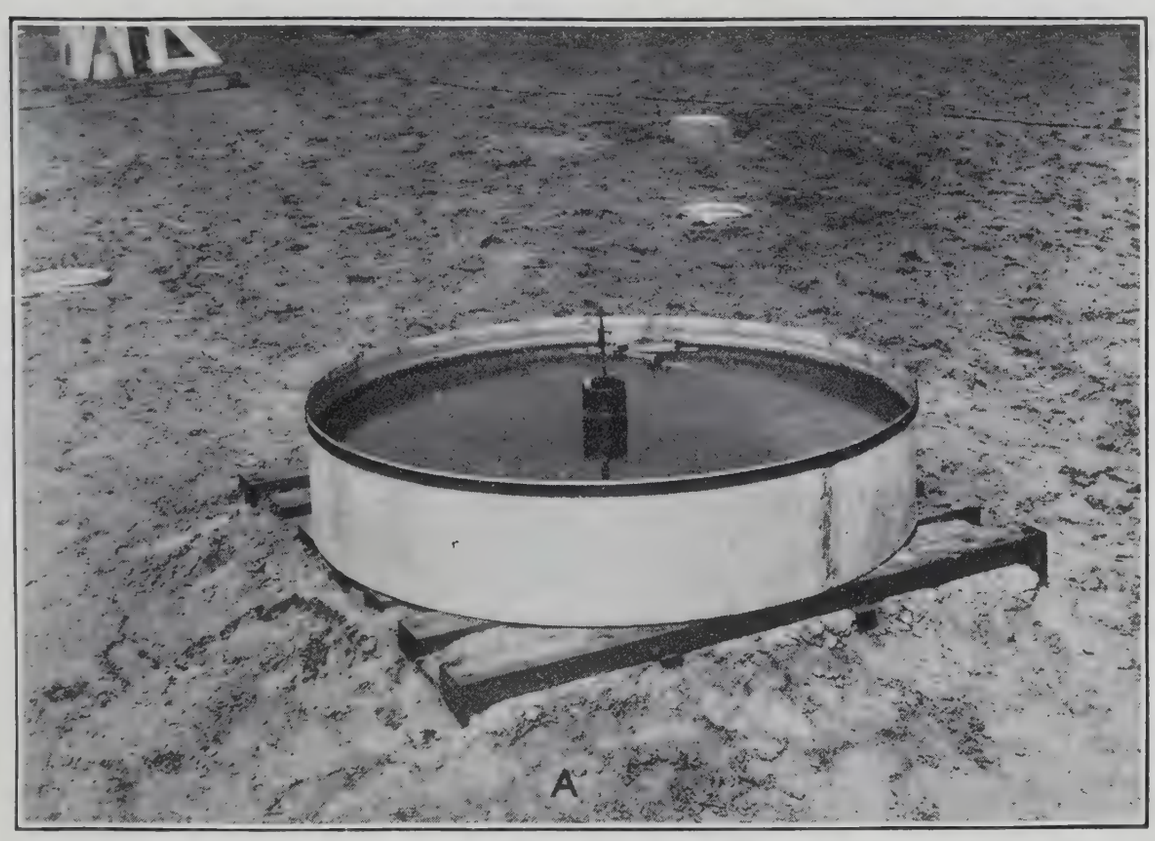
PLATE 36

A.—Apparatus used for comparison between still and flowing water, together with tanks 8, 15, and 3.

B.—A heated evaporation tank similar to No. 23, 24, and 25.

PLATE 37

A.—United States Weather Bureau standard pan for class A station.
B.—United States Geological Survey standard floating tank.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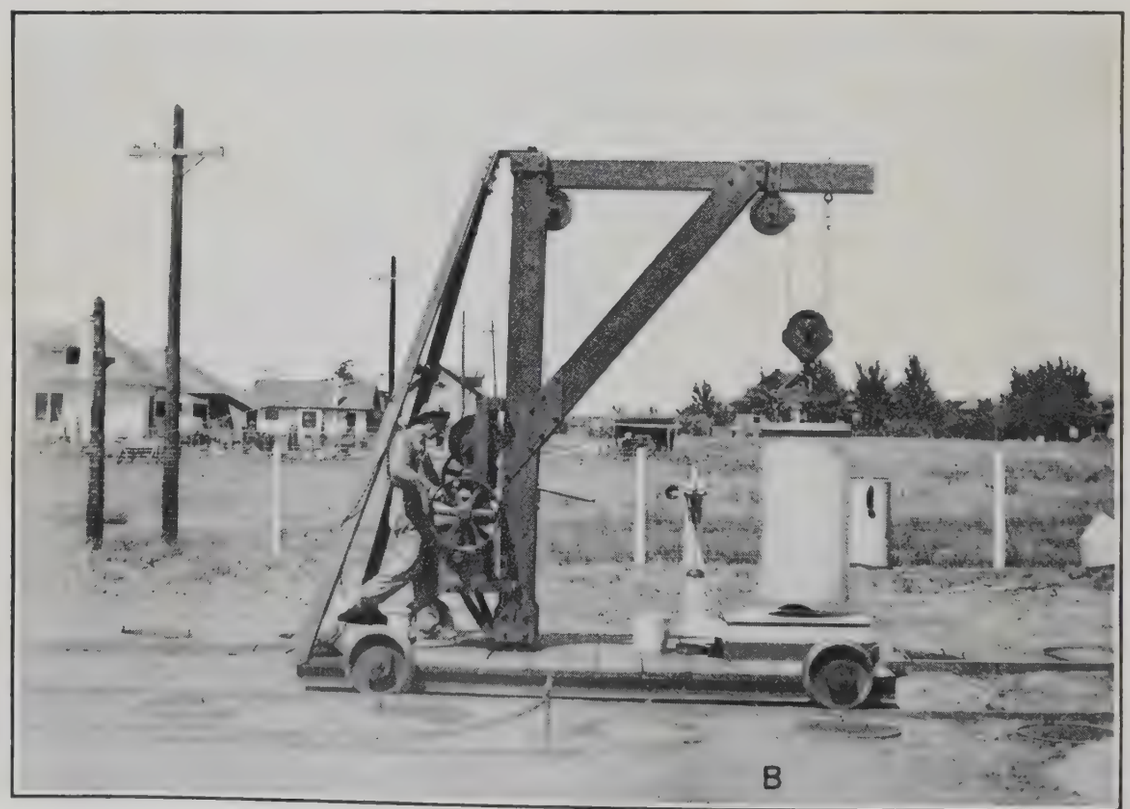
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PLATE 38

A.—Water-jacketed evaporation tanks of the Fortier type.
B.—Apparatus for weighing tanks.

INFLUENCE OF GRADING ON THE VALUE OF FINE AGGREGATE USED IN PORTLAND CEMENT CONCRETE ROAD CONSTRUCTION

By F. H. Jackson, Jr.,

Assistant Testing Engineer, Office of Public Roads and Rural Engineering, United States Department of Agriculture

THE PROBLEM

Everyone familiar with either the testing of cement concrete or its practical use in various forms of construction realizes the marked effect variations in the grading of the aggregates may have on its strength, density, and other properties. It is known, for instance, that, other things being equal, the use of a coarse sand combined with a uniformly graded coarse aggregate will result in the production of a very much better grade of concrete than will the use of either a fine sand, a poorly graded coarse aggregate, or both. The importance of this matter, with special reference to the use of concrete as a road-surfacing material, has been much emphasized recently before engineering societies and elsewhere. The conclusions so far drawn, however, are apparently based upon the generally accepted principle as applied to the ordinary use of concrete rather than upon definite tests made with the object of determining the effect of variations in either the quality or grading of the aggregate on the resistance of concrete to the peculiar destructive forces encountered on a road. It is, of course, apparent that these forces are not only more severe but are more varied than those which act upon unreinforced concrete as ordinarily used, which is usually subjected only to direct compression.

Agencies particularly destructive to a concrete road are (1) traffic, (2) weather, and (3) constructional defects, all of which produce stresses in the concrete which should be taken care of as completely as possible through an intelligent selection of materials as well as a proper observance of the details of construction.

Traffic operates as a destructive force in three ways: (1) Iron tires cause an abrasion or grinding away of the particles composing the surface of the pavement, which varies inversely with the hardness of the concrete. (2) Suddenly applied loads, horses' hoofs, etc., subject the pavement to impact, tending to loosen and sometimes fracture the individual fragments composing the aggregate, and is resisted by the property of toughness in the material. (3) The actual weight of traffic as transmitted by wheel loads produces also compressive stresses proportional to the unit loads, but these are of much less importance in causing

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wear than are the stresses produced by abrasion and impact. The combined destructive effect of abrasion and impact therefore may be called the effect of wear, so that any concrete which will successfully resist these two forces may be said to possess high resistance to wear.

The influences of the weather tend to stress the concrete sometimes in tension and sometimes in compression, either through the action of temperature or moisture changes, or both, and usually result in the formation of cracks whose edges, unless adequately maintained, subsequently wear rapidly under the action of traffic.

Constructional defects usually result in unduly stressing the concrete at some particular point, such as might be caused by settlement due to improper consolidation of the subbase. Traffic undoubtedly is the most important destructive agency in so far as the ultimate life of the road is concerned, because its effects are cumulative and also serve to hasten deterioration started from other causes. With this point in mind, it follows that a determination of the suitability of concrete for use as a road material should be essentially a determination of its resistance to wear; and, since resistance to wear means both resistance to abrasion and impact, it would seem that hardness, and toughness tests, or a single test combining both, should be logical ones to apply.

It is the purpose of this paper to present some results obtained recently in the laboratory of the Office of Public Roads and Rural Engineering, which show in a general way the possible effect of variations in the grading of fine aggregate on each of these essential properties. Of course, it is realized that grading is only one of a number of properties of the aggregates which may influence the quality of the finished product. The character of the particles themselves, whether they are of a hard siliceous or soft calcareous nature, as well as the amount of impurities, organic or otherwise, present, is of the utmost importance. In the following tests, however, these influences were controlled by the use of a standard aggregate which was artificially graded in the laboratory prior to use.

In the case of rock used in macadam-road construction the nature of the material is such that its hardness and toughness may be determined readily, either by means of independent tests or by means of a wear test in which both properties are measured. These tests have become well known, but, because the principles involved have been used in this work, they will be discussed very briefly here. The hardness of a rock is determined by subjecting a cylindrical specimen, prepared by means of a diamond drill, to the abrasive action of crushed quartz sand of a definite size. The rock cylinder is held against a horizontally revolving steel disk upon which the abrasive is fed. The loss in weight is determined after a given number of revolutions, and this loss is used as an index of the hardness of the material.

Toughness is measured by subjecting a cylindrical rock core, 1 by 1 inch in size, to the impact produced by the fall of a given weight through successively increasing heights until failure occurs.

The combined effects of both abrasion and impact are measured together by means of the well-known Deval abrasion test, in which a standard weight of material is rattled in a cast-iron drum in such a way that the pieces composing the sample are subjected to both influences. The weight of charge larger than a certain size after a given number of revolutions measures the resistance to wear.

From a consideration of these tests it is seen at once that, with the exception of rock or slag, they are not adapted to a direct determination of the quality of concrete aggregates. The Deval test in modified form has been used to determine the resistance to wear of gravel and sand, but its use for this purpose, though promising, still is in the experimental stage. It is manifestly impossible to test the wearing qualities of fine aggregates directly by any of these methods. Either the hardness or toughness test or a wear test may, however, be applied to the fine aggregate when combined with cement to form a mortar or with cement and coarse aggregate to form concrete. Wear tests of mortar and concrete have been made with the Deval machine, the Tablot-Jones brick rattler, and other special devices. Of these the adaptation of the brick rattler as described by Abrams [1] appears to be the nearest solution of the problem of obtaining a laboratory wear test. Only preliminary results of tests using this method have been published. Wear tests of concrete in place on the road have been confined largely to suggestions for suitable methods, although tests using the apparatus designed by Goldbeck [2] have been started on an experimental concrete road near Washington, D. C.

EXPERIMENTAL WORK

In the following tests the effect of varying the grading of sand on the hardness, toughness, tensile strength, and crushing strength of mortars has been studied. The fine aggregate was prepared by artificially grading a quantity of Potomac River concrete sand, the analysis of which is shown in Table I into three sizes as follows:

(1) A coarse sand (*C*) composed of equal parts of material passing a ¼-inch screen but retained on a 10-mesh sieve and that passing a 10-mesh but retained on a 20-mesh sieve.

(2) A medium sand (*M*) composed of equal parts of 20 to 30 mesh, 30 to 40 mesh, and 40 to 50 mesh material.

(3) A fine sand (*F*) composed of the run of the sand below No. 50.

[1] ABRAMS, D. A. A METHOD OF MAKING WEAR TESTS OF CONCRETE. *In* Amer. Soc. Testing Materials Proc. 19th Ann. Meeting, 1916, v. 16, pt. 2, p. 194–202. 1916.

[2] GOLDBECK, A. T. APPARATUS FOR MEASURING THE WEAR OF CONCRETE ROADS. *In* Jour. Agr. Research, v. 5, no. 20, p. 951–954, pl. 66. 1916.

TABLE I.—*Mechanical analysis of natural sand*

Mesh of sieve.	Percentage passing.	Mesh of sieve.	Percentage passing.
Between ¼ inch and No. 10	15.9	Between No. 80 and 100	2.4
Between No. 10 and 20	21.8	Between No. 100 and 200	3.3
Between No. 20 and 30	21.2	Under 200	2.8
Between No. 30 and 40	13.3		
Between No. 40 and 50	7.9	Total	100.0
Between No. 50 and 80	11.4		

The fine sand contained about 10 per cent that passed a 200-mesh sieve.

The sands graded as above then were recombined into 60 different combinations of coarse, medium, and fine, as shown in Table II, in which the equivalent mechanical analysis of each combination is also shown. The resulting sands were made up into standard mortar briquettes and 2 by 2 inch cylinders, using a mixture composed of 1 part of cement to 2½ parts of sand. All the batches were brought to as nearly the same consistency as it was possible to judge by the eye, which necessitated the use of varying percentages of water. Specimens were stored in moist air one day and in water six days and then were tested to determine their hardness, toughness, tensile strength, and crushing strength.

TABLE II.—*Proportion of artificially graded sands*

Laboratory No.	Proportions.			Equivalent mechanical analysis—per cent between—					
	C.	M.	F.	¼-inch and No. 10.	10 and 20.	20 and 30.	30 and 40.	40 and 50.	Under No. 50.
	Per ct.	*Per ct.*	*Per ct.*						
1	100	0	0	50	50	0	0	0	0
2	80	0	20	40	40	0	0	0	20
3	80	10	10	40	40	3.3	3.3	3.3	10
4	80	20	0	40	40	6.6	6.6	6.6	0
5	70	0	30	35	35	0	0	0	30
6	70	10	20	35	35	3.3	3.3	3.3	20
7	70	20	10	35	35	6.6	6.6	6.6	10
8	60	0	40	30	30	0	0	0	40
9	60	10	30	30	30	3.3	3.3	3.3	30
10	60	20	20	30	30	6.6	6.6	6.6	20
11	60	30	10	30	30	10	10	10	10
12	60	40	0	30	30	13.3	13.3	13.3	0
13	50	0	50	25	25	0	0	0	50
14	50	10	40	25	25	3.3	3.3	3.3	40
15	50	20	30	25	25	6.6	6.6	6.6	30
16	50	30	20	25	25	10	10	10	20
17	50	40	10	25	25	13.3	13.3	13.3	10
18	40	0	60	20	20	0	0	0	60
19	40	10	50	20	20	3.3	3.3	3.3	50
20	40	20	40	20	20	6.6	6.6	6.6	40
21	40	30	30	20	20	10	10	10	30
22	40	40	20	20	20	13.3	13.3	13.3	20
23	40	50	10	20	20	16.6	16.6	16.6	10

TABLE II.—*Proportion of artificially graded sands*—Continued

Laboratory No.	Proportions.			Equivalent mechanical analysis—per cent between—					
	C.	M.	F.	¼-inch and No. 10.	10 and 20.	20 and 30.	30 and 40.	40 and 50.	Under No. 50.
	Per ct.	*Per ct.*	*Per ct.*						
24	40	60	0	20	20	20	20	20	0
25	30	0	70	15	15	0	0	0	70
26	30	10	60	15	15	3.3	3.3	3.3	60
27	30	20	50	15	15	6.6	6.6	6.6	50
28	30	30	40	15	15	10	10	10	40
29	30	40	30	15	15	13.3	13.3	13.3	30
30	30	50	20	15	15	16.6	16.6	16.6	20
31	30	60	10	15	15	20	20	20	10
32	20	0	80	10	10	0	0	0	80
33	20	10	70	10	10	3.3	3.3	3.3	70
34	20	20	60	10	10	6.6	6.6	6.6	60
35	20	30	50	10	10	10	10	10	50
36	20	40	40	10	10	13.3	13.3	13.3	40
37	20	50	30	10	10	16.6	16.6	16.6	30
38	20	60	20	10	10	20	20	20	20
39	20	70	10	10	10	23.3	23.3	23.3	10
40	20	80	0	10	10	26.6	26.6	26.6	0
41	10	0	90	5	5	0	0	0	90
42	10	10	80	5	5	3.3	3.3	3.3	80
43	10	20	70	5	5	6.6	6.6	6.6	70
44	10	30	60	5	5	10	10	10	60
45	10	40	50	5	5	13.3	13.3	13.3	50
46	10	50	40	5	5	16.6	16.6	16.6	40
47	10	60	30	5	5	20	20	20	30
48	10	70	20	5	5	23.3	23.3	23.3	20
49	10	80	10	5	5	26.6	26.6	26.6	10
50	0	0	100	0	0	0	0	0	100
51	0	10	90	0	0	3.3	3.3	3.3	90
52	0	20	80	0	0	6.6	6.6	6.6	80
53	0	30	70	0	0	10	10	10	70
54	0	40	60	0	0	13.3	13.3	13.3	60
55	0	50	50	0	0	16.6	16.6	16.6	50
56	0	60	40	0	0	20	20	20	40
57	0	70	30	0	0	23.3	23.3	23.3	30
58	0	80	20	0	0	26.6	26.6	26.6	20
59	0	90	10	0	0	30	30	30	10
60	0	100	0	0	0	33.3	33.3	33.3	0

HARDNESS TESTS

Specimens for the hardness tests were prepared by drilling 1-inch cores through the center of the 2-inch cylinders and drying them thoroughly in a hot-air oven. They were tested then for hardness in the same manner as the hardness of rock is obtained, as described above, by holding the ends of the specimens against a revolving steel disk upon which quartz sand was fed as the abrasive. The specimens were weighed carefully before and after 1,000 revolutions of the disk, and the loss in weight was used as an index of the hardness of the mortar. The results of the hardness tests on all the sand mixtures studied are shown

in figure 1, in which the loss in weight of the various specimens is plotted on a Feret triangle at the points indicating the proportions of coarse, medium, and fine sand in the mix. Several interesting facts are shown in this figure. First, it is seen that the loss in weight of all specimens is practically constant for all mixtures containing more than 10 per cent of the coarse sand. This loss, averaging about 5 gm., is very slightly more than would be obtained on a specimen of solid quartz tested in the same way. In other words, the hardness of all specimens containing an appreciable amount of sand over 20 mesh in size appears to be a function of the hardness of the aggregate itself independent of the grading. On referring to the specimens containing various percentages of medium and fine sand, but no coarse, it will be noted that the loss in weight is very much greater, amounting in two cases to more than 250 gm. By assuming that the actual hardness of the coarse and medium sand grains is the same, in view of the fact that the sand was composed of practically pure quartz, these results show that the use of the fine sand has so weakened the adhesion between the cement and the individual particles of aggregate by enormously increasing its superficial area that the specimens disintegrated readily under the action of the abrasive.

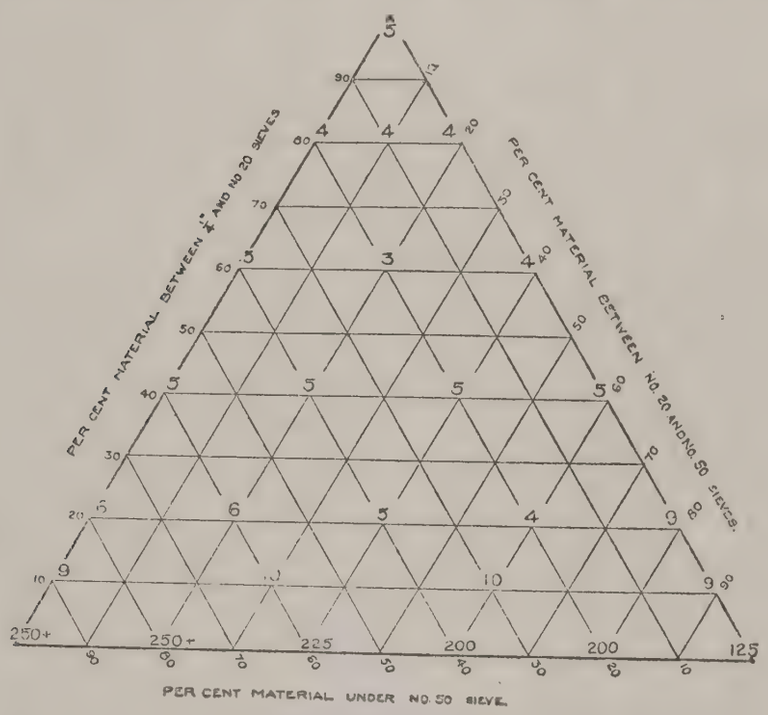

FIG. 1.—Graph of hardness tests of artificially graded sand mortar. Proportions 1 to 2½ by weight.

In order to determine the hardness of mortar containing very fine sand in a rich mix, as compared to the 1-to-2½ mixes, a few tests were made using sands artificially graded as above in the proportion of 1 part of cement to 1½ parts of sand. In the case of mixtures containing coarse sand, losses practically identical with those shown on figure 1 were found. In the case of the very fine sands, however, an average loss of about 40 instead of 200 was noted. This would indicate that the hardness of a mortar containing a large amount of extremely fine sand may be increased considerably by increasing the quantity of cement. Even in this case, however, the average loss is greatly in excess of that obtained by the use of a coarse sand.

In figure 2 the results of the 1-to-2½ mortar tests are shown plotted on rectangular coordinates with the percentage of sand over 20 mesh as abscissæ and the loss in weight per 1,000 revolutions as ordinates. Each point plotted represents the average of the results on all values obtained originally with the percentage of coarse sand as indicated. For instance, the average of all combinations of medium and fine sand with 20 per cent coarse showed a loss of 6 gm., and this value is plotted on the curve. This graph shows the great effect of coarse sand on the hardness of mortar. The corresponding curve (not shown) for the hardness of 1-to-1½ mortars was found to be practically identical, except that the average loss for mortars containing no percentage of sand over 20 mesh was 40 instead of 200.

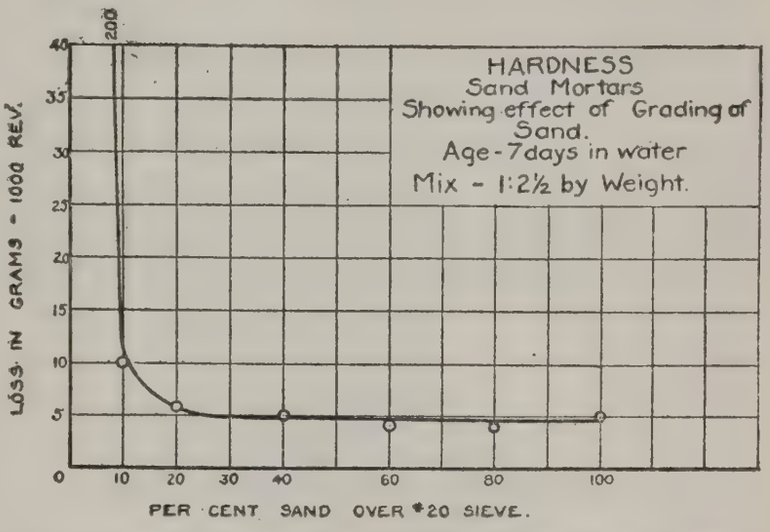

FIG. 2.—Curve of hardness tests of artificially graded sand mortar.

Figure 3 shows the results of a number of hardness tests made on a series of mortar specimens, in which the grading of the sand remained constant and the percentage of cement varied. In these tests the unscreened Potomac River sand, similar in quality to the artificially graded sands, was used. It will be seen that the hardness values of the mortar specimens are all greater than neat cement. Furthermore, there is very little difference in the loss in weight between the 1-to-1, 1-to-1½, 1-to-2, and 1-to-3 mixes, all of which show about the same hardness as was obtained with the artificially graded coarse sands. The somewhat greater loss sustained by the 1-to-4 mortar specimen, no doubt, is due to the very lean mix, which allowed the mortar to disintegrate under the test in much the same way as noted above for very fine sand.

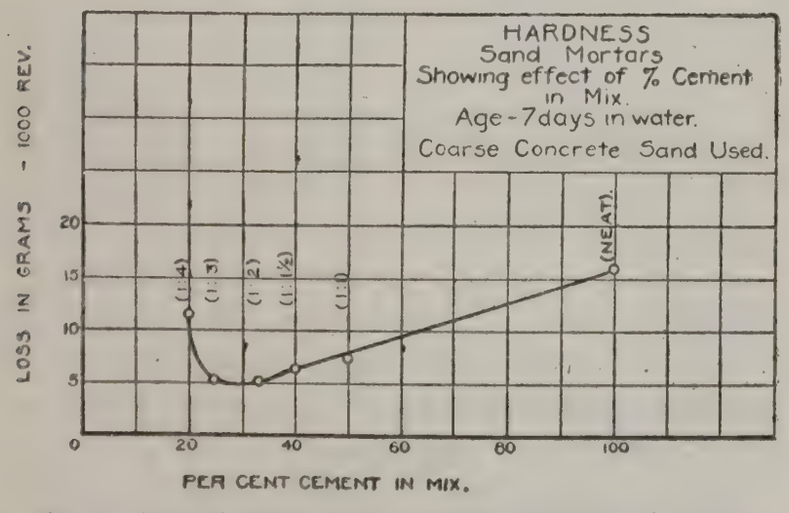

FIG. 3.—Curve of hardness tests of natural concrete sand mortars.

TOUGHNESS TESTS

Toughness tests were made on 2- by 2-inch cylinders, using the Page impact machine for testing rock. The procedure was similar to that employed in the standard rock test, except that a 2-inch instead of a 1-inch cylinder and a ½ instead of a 2 kgm. hammer were used. The test consisted of a 1-cm. fall of the hammer for the first blow, followed by a 2-cm. fall, etc., until the cylinder was fractured. The height of blow at failure in centimeters was used as an indication of the relative toughness of the mortar. The results of tests are plotted in figure 4, using the Feret triangle. Each result plotted is the average of three tests. An inspection of the diagram shows at once that considerable variation in toughness may be obtained, owing to differences in sand grading, but that, in general, toughness increases with the percentage of coarse sand in the mix. The contour lines, which bound areas of equal toughness, show in a general way the relative resistance to impact developed by the use of different mixtures. The area of maximum toughness is seen at the top of the triangle and includes sand having from 60 to 90 per cent of coarse, from 0 to 20 per cent of medium, and from 5 to 35 per cent of fine material. The area of minimum toughness, as would be expected, lies toward the lower left-hand corner and includes the very fine sands. It may be noted also that, with a given percentage of coarse sand, say 50, the highest results were obtained when the proportions of medium and fine sand were about equally divided. On the other hand, for a given percentage of either medium or fine sand, the toughness appears to increase as the proportion of coarse sand increases. In general, it would seem that the toughness of a cement mortar increases with the amount of coarse sand present in the aggregate up to the limit of maximum toughness, which, for this mix appears to be obtained with a sand having about 80 per cent of coarse, 10 per cent of medium, and 10 per cent of fine material. The general effect of coarse sand on toughness is shown clearly in figure 5, which is replotted from the results shown

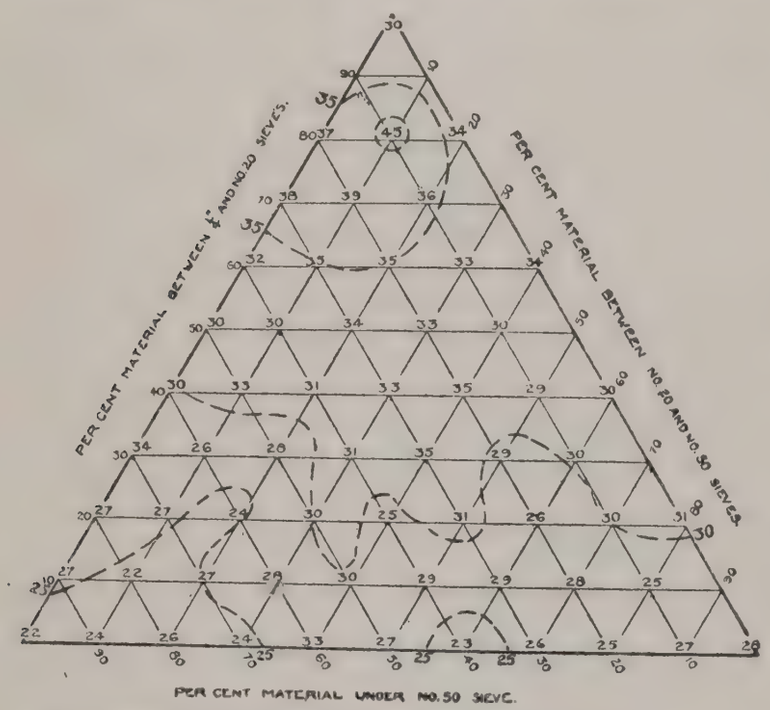
PER CENT MATERIAL BETWEEN ¼ AND NO.20 SIEVES.
PER CENT MATERIAL BETWEEN NO.20 AND NO.50 SIEVES.
PER CENT MATERIAL UNDER NO.50 SIEVE.

FIG. 4.—Graph of toughness tests of artificially graded sand mortar. Proportions 1 to 2½ by weight.

in figure 4 in the same way as the results of the hardness tests previously referred to.

A series of tests made with the view of determining the effect of richness of mix on the toughness of cement mortar are shown, for comparison, in figure 6. The results are plotted with the percentage of cement as abscissæ and toughness as ordinates. Each plotted result is the average of nine tests. These results are of interest in showing the large increase in toughness produced by increasing the cement content. This increase appears to be practically proportional to the percentage of cement up to a 1-to-1 mix, after which the addition of more cement affects the toughness very little. In other words, a neat cement briquette is no tougher than one composed of equal parts of cement and a typical concrete sand, which, in turn, shows twice the resistance to impact of one containing only 20 per cent. Inasmuch as this sand was very well graded and contained only 35 per cent of voids, it is obvious that a considerable excess of cement over that required to fill the voids is required to reach the condition of maximum toughness. In other words, these results present an experimental verification of the theory which requires the use of a rich mix in the surface of a concrete pavement, especially as has been seen by reference to the hardness test shown in figure 3 that the hardness of a rich 1-to-1½ mix is practically the same as a 1-to-3 and greater than a 1-to-4 mix.

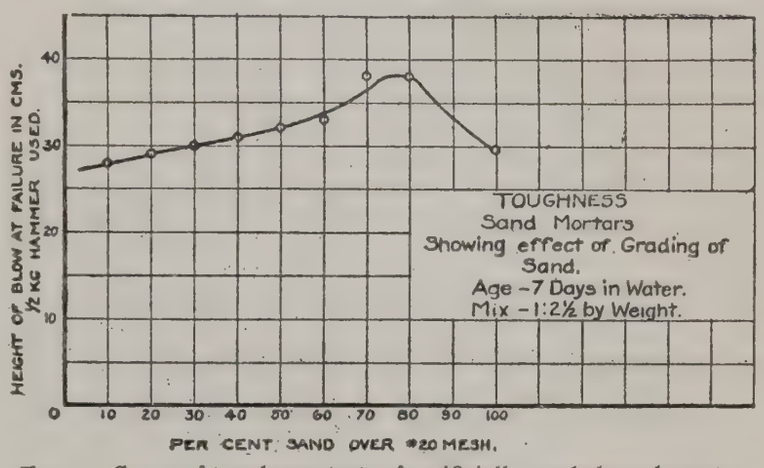

FIG. 5.—Curve of toughness tests of artificially graded sand mortar.

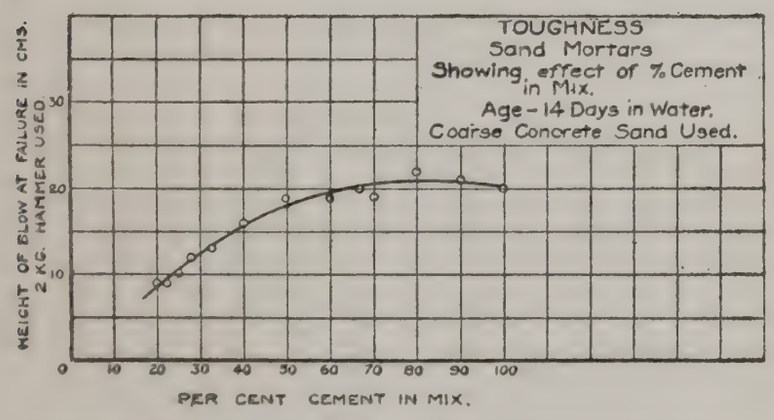

FIG. 6.—Curve of toughness tests of natural concrete sand mortar.

TENSION AND COMPRESSION TESTS

The results of the tension and compression tests are shown in figures 7 and 8. They were made in the usual way on standard briquettes and 2 by 2 inch cylinders. Each value in tension is the average of six tests,

and each value in compression the average of three tests. The average total variation in individual results of each set was 10 per cent for tension and 5 per cent for compression. The results show graphically the enormous variation which may be obtained in both the tensile and compressive strength of mortar by reason of variations in the grading of the sand. The contour lines are much more regular than those showing variations in toughness. The following points may be noted:

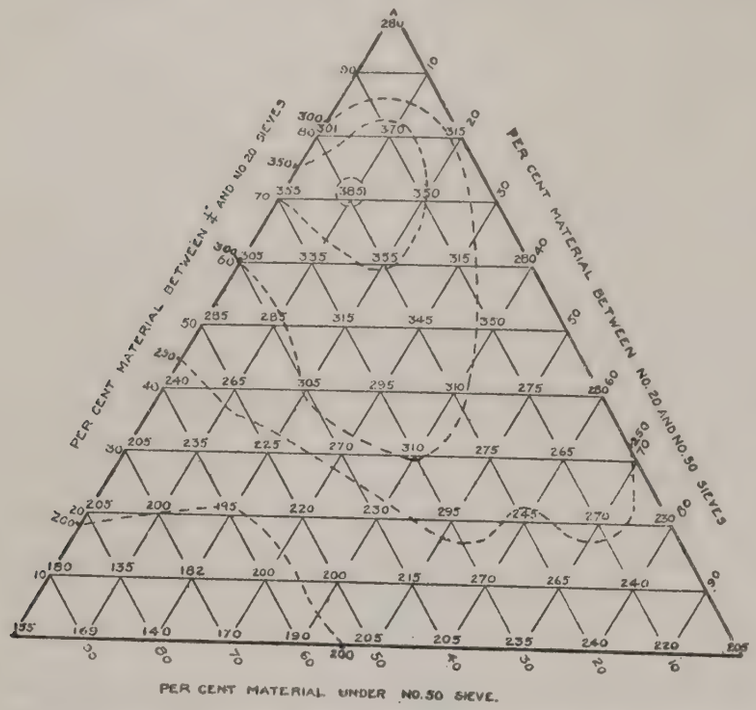
PER CENT MATERIAL BETWEEN ¼" AND NO.20 SIEVES.
PER CENT MATERIAL BETWEEN NO.20 AND NO.50 SIEVES.
PER CENT MATERIAL UNDER NO.50 SIEVE.

FIG. 7.—Graph of tension tests of artificially graded sand mortars. Proportions 1 to 2½ by weight.

TENSION.—Sands showing maximum results in tension are composed of from 60 to 80 per cent coarse, 0 to 20 per cent medium, and 10 to 30 per cent fine, whereas the weakest sands are those composed of from 0 to 10 per cent coarse, 0 to 20 per cent medium, and 80 to 100 per cent fine. A sand composed of 100 per cent coarse is 35 per cent stronger than one composed of medium only and 80 per cent stronger than one composed of fine only, but is nearly 40 per cent weaker than the sand of maximum strength (70–10–20). The total variation in strength is 250 pounds per square inch, or 54 per cent from the average of the 60 determinations.

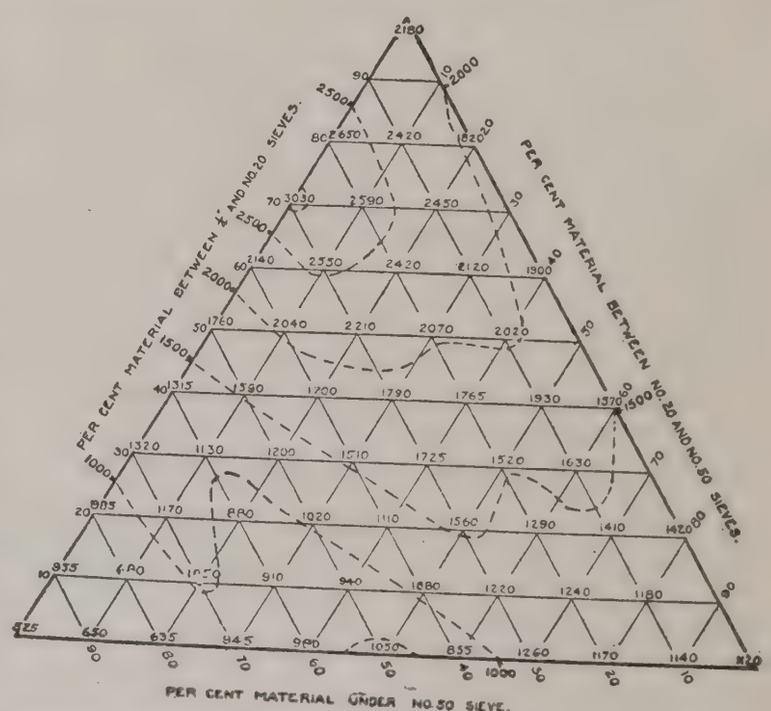
PER CENT MATERIAL BETWEEN ¼" AND NO.20 SIEVES.
PER CENT MATERIAL BETWEEN NO.20 AND NO.50 SIEVES.
PER CENT MATERIAL UNDER NO.50 SIEVE.

FIG. 8.—Graph of compression tests of artificially graded sand mortars. Proportions 1 to 2½ by weight.

COMPRESSION.—Sands showing maximum results in compression are composed of from 60 to 80 per cent coarse, 0 to 20 per cent medium and 10 to 30 per cent fine, the same limits as for tension. A sand composed

of 100 per cent coarse is 95 per cent stronger than one composed of fine only, but is 35 per cent weaker than the strongest sand (70–0–30). The total variation in strength is 2,505 pounds per square inch, or 100 per cent from the average of 60 determinations.

In figures 9 and 10 the results of the tension and compression tests are replotted on rectangular coordinates to show the effect of the coarse sand (¼ inch to No. 20 mesh) on the strength of the mortar. The most interesting feature about these curves, apart from their regularity, is the very great variation in strength shown, especially in compression. Thus, without considering either the very coarse or very fine sand, which would be used rarely in actual construction, the variations in strength are still large. Let it be assumed, for instance, that a specification calls for a sand which shall show from 20 to 50 per cent retained on the No. 20 sieve. The results of these tests show a possible variation in compression of from 1,200 to 2,000 pounds per square inch for sands fulfilling this requirement. They show also that much higher strength may be obtained in the mortar by the use of coarser sands up to as high as 70 per cent retained on a 20-mesh sieve.

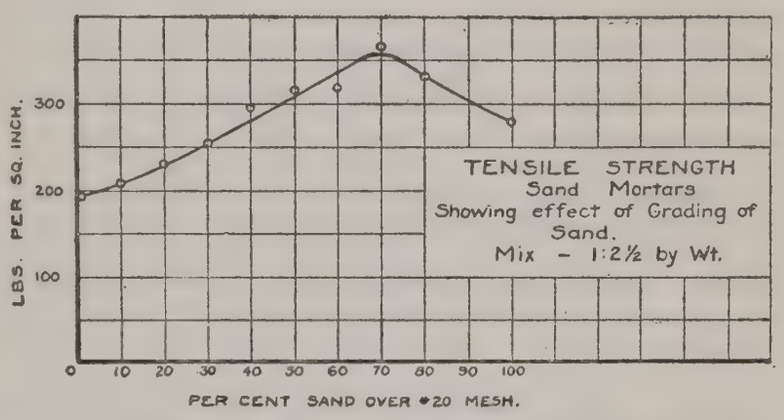

FIG. 9.—Curve of tension tests of artificially graded sand mortars.

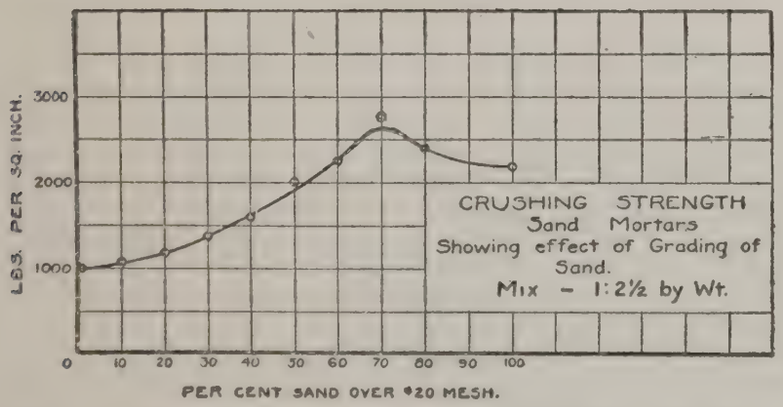

FIG. 10.—Curve of compression tests of artificially graded sand mortars.

It is realized, of course, that such coarse sands seldom are met with in practice and, if they were, would not be used in ordinary work where a considerable amount of fine material is needed to produce workability. It must be borne in mind, however, that concrete-pavement construction is not ordinary work on account of the severity and variety of the destructive forces encountered. It has been the custom to meet this condition by increasing the amount of cement to about 40 per cent of the mortar in a 1-to-5 mix, and, while this is good practice, it seems reasonable to suppose that a still greater resistance to these destructive agencies would be obtained by increasing the amount of the coarse sand which takes this wear (the ¼ inch to 20-mesh material) over that which is usually considered good

practice. This would seem to be allowable, especially in view of the large excess of cement that is always used. When one considers that a large proportion of the wearing surface of a concrete pavement is composed of mortar, the danger of using a fine sand, with subsequent weakening of the matrix, is apparent.

In the foregoing discussion it is realized that but few naturally occurring concrete sands are as coarse as those making the strongest mortars, according to these tests. Neither has the fact been overlooked that the best mortar, when combined with stone or gravel, without reference to its grading, will not necessarily produce the best concrete. A poorly graded coarse aggregate will unquestionably require more mortar than will a well-graded one. Likewise, a coarse aggregate containing a large amount of small stone will allow the use of a somewhat finer sand than when the larger-sized stones predominate. When it is considered, however, that the mortar in concrete forms a matrix by which the larger stones are held in place, that this matrix occupies nearly one-half the total volume of the concrete, and, finally, that its strength and toughness are undoubtedly influenced to a large degree by the grading of the sand, the discussion becomes of practical value. So important does it become that it might even be considered practical to use a graded rather than a naturally occurring concrete sand in such important work as concrete-road construction if by so doing the life of the pavement can be prolonged.

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CHEMICAL STUDIES IN MAKING ALFALFA SILAGE

By C. O. SWANSON, *Associate Chemist*, and E. L. TAGUE,[1] *Assistant Chemist, Department of Chemistry, Kansas Agricultural Experiment Station*

INTRODUCTION

This paper is a preliminary report on chemical studies in making alfalfa silage. The complete report will appear as a publication of the Kansas Experiment Station. There were two phases of these experiments: One phase was conducted by the Department of Chemistry with quart milk bottles as containers for the silage. The other phase was conducted with seven 10-ton experimental silos in cooperation with the Departments of Bacteriology and Dairy Husbandry,[2] the latter of which built and owns the experimental silos. The first phase of the work was begun in 1912 and continued for four years. The second phase of the work was begun in 1914 and was continued in 1915. In this paper will be given briefly the work of the first three years, followed by a more detailed statement of both phases of the work for 1915.

PART I.—EXPERIMENTS WITH ALFALFA SILAGE MADE IN QUART MILK BOTTLES

PRELIMINARY TRIALS IN 1912 AND 1913

In 1912 only a few preliminary trials were made, but they showed the possibility of success in making silage from alfalfa if the right conditions are discovered. In 1913, 23 bottles were filled, some with alfalfa alone and some with alfalfa plus accessory materials. These materials were corn chop and rye, of which different proportions were used. Some of the alfalfa was merely put through the feed cutter, which made a somewhat finer material than is obtained from the ordinary

[1] Other men in the Department of Chemistry who have been associated with this work are: J. W. Calvin, formerly Assistant Chemist, but now with the University of Nebraska; J. C. Summers, formerly Assistant Chemist, but now with the Operative Miller; J. H. Young, formerly a graduate student, now with Ohio State University, and F. A. Gougler, formerly a graduate student, now County Agent, Johnson County, Missouri.

[2] The authors wish to express their appreciation of the helpful cooperation from Professors O. E. Reed and J. B. Fitch, of the Department of Dairy Husbandry, and Professors L. D. Bushnell and O.W. Hunter, of the Department of Bacteriology. Acknowledgments are also due President H. J. Waters and Dean J. T. Willard for valuable suggestions.

silage cutter. Some of the alfalfa was ground in a large power sausage mill after first being put through the feed cutter. Water was added to these bottles to test the influence of more moisture. The prepared material was compressed in the milk bottles by means of a broom handle, which made a fairly tight packing. Each bottle contained about 1½ pounds of material. No attempt was made in this trial to get exactly the same amount in each bottle. After packing, the mouth was closed with an ordinary cork, which was made fast by wiring with copper wire and sealed with wax such as is used in sealing desiccators.[1] In most of the bottles, as soon as fermentation began, the cork would be pushed out sufficiently to allow the escape of the accumulated gas. The bottles had to be rewired several times. After about two weeks the bottles would stay wired and sealed. These bottles were filled on May 2, 1913, and were opened on January 2, 1914.

QUALITY OF SILAGE PRODUCED

When the bottles were opened, the materials were examined by several persons. Of the 23 bottles, 5 contained silage that was good, and 2 very good. The silage in these two consisted of alfalfa alone ground very fine, the only difference between the two being that the alfalfa in one contained more moisture than that in the other. All of the bottles which contained corn as a part of the mixture graded good. Eight of the bottles graded fair, five bad, and only one very bad. Seven of those that graded fair contained rye as a part of the mixture. But for the strong odor of the rye this silage would have graded good. Rye alone, alfalfa alone cut in the feed cutter, rye and alfalfa with the addition of water, and alfalfa alone plus water all made bad or very bad silage. The addition of water was harmful in all cases this year. In later trials this was not the case. After examination and sampling for analysis, portions of the different kinds were offered to dairy cows. The good and very good were readily eaten. That which graded fair was partially or indifferently eaten.

MOISTURE AND ACIDITY

Five of the bottles which had bad and very bad silage had a moisture content above 75 per cent, while the only bottles of bad silage with a low moisture content were those containing rye alone. A too high or too low water content did not produce good silage. All but one of the bad and very bad bottles of silage had a low percentage of acidity, the only exception being the mixture of alfalfa, rye, and water. All the bottles of silage which graded good had a high percentage of acidity.

[1] This wax is a mixture of 70 parts, by weight, of beeswax, 15 parts of Venice turpentine, and 15 parts of vaseline.

CONCLUSIONS FROM THE WORK OF 1913

The results of the 1913 work show that alfalfa alone makes good silage when finely ground and tightly packed. These conditions are such, however, that it is impossible to realize them in practice. Rye in combination with alfalfa made a fair silage, except for the odor of the rye. Alfalfa alone coarsely ground and loosely packed did not make good silage. Corn chop added to the alfalfa made conditions suitable for good silage to such an extent that there is a possibility of practical realization. The addition of water to green alfalfa was in all cases harmful.

TRIALS TO DETERMINE THE INFLUENCE OF MATURITY

Whether the stage of maturity enters into the conditions for making silage from alfalfa was investigated in the summer of 1914. Alfalfa was cut at four stages of maturity—in the bud, in one-tenth bloom, in full bloom, and in seed—12 bottles of each stage being put up. The alfalfa was all cut in the feed cutter. The 12 conditions were as follows: (1) green alfalfa tightly packed; (2) green alfalfa loosely packed; (3) wilted alfalfa tightly packed; (4) wilted alfalfa tightly packed plus water; (5) corn meal from sound corn and alfalfa in the proportion of 1 to 10; (6) corn meal from germinated corn and alfalfa, 1 to 10; (7) corn meal from germinated corn and alfalfa, 1 to 20; (8) molasses [1] and alfalfa, 1 to 10; (9) molasses and alfalfa, 1 to 20; (10) molasses and alfalfa, 1 to 30; (11) acetic acid and alfalfa, 1 to 50; and (12) lactic acid and alfalfa, 1 to 50. Conditions under 5, 6, and 7 would answer the question whether the more easily fermentable carbohydrates in germinated corn would be more effective than the carbohydrates of sound corn, as well as to show how small an amount of carbohydrate was necessary in order to have the conditions which would produce the requisite amount of acid.

QUALITY OF SILAGE PRODUCED

The bottles were put up in May and opened the following December, and at that time the quality of silage was judged by several persons, as in the previous year. When supplements were added to the alfalfa, the results were 100 per cent good or very good. Molasses as a supplement produced a silage of milder and sweeter odor than did corn meal. The two acids used gave a silage with a sharp acid odor. Corn meal gave an odor that was rather strongly acid. The germinated corn meal gave a sweeter odor, somewhat similar to the molasses. The percentage of good silage when alfalfa was used alone was only 25 for the last three stages, and less than that for the bud stage. Observations made at the time that the bottles were opened were to the effect that the quality of the silage from the bud stage was inferior to that of the three other stages. This experiment showed that alfalfa is suitable for making silage when it is best for hay making.

[1] The use of molasses was suggested to the authors by President Waters.

MOISTURE AND ACIDITY

The figures obtained in the moisture determinations showed that the amount of moisture present may be a favorable condition for the development of the proper amount of acidity, but it is not by itself a determining factor. The general average showed that the bud stage had the highest amount of moisture, that the tenth-bloom and the full-bloom stages were practically equal, and that the seed stage had the lowest amount. These moisture percentages are consistent with the changes in the alfalfa as it matures.

The general average percentage for acidity showed that a high moisture content or a low-moisture content did not necessarily correspond to a proportional development of acidity. The acidity figures also showed that alfalfa alone gave the lowest percentage, and that alfalfa and corn gave the highest percentage.

CONCLUSIONS FROM THE WORK OF 1914

The experiments showed that alfalfa was suitable for making silage when mature enough for making hay; that it was possible to make silage from alfalfa alone when coarsely cut and tightly packed, but in such conditions success was obtained only once in four cases; that if substances containing fermentable carbohydrates were added, the chances of success were 100 per cent.

EXPERIMENTS TO DETERMINE INFLUENCE OF WILTING, TIGHTNESS OF PACKING, ADDITION OF WATER, AND ADDITION OF VARIOUS SUPPLEMENTS

In the spring of 1915, 132 bottles [1] were filled under as many conditions. There were four degrees of tightness of packing, making four bottles in each set. The first bottle was packed as full as possible, and the weight of alfalfa in each was determined. Into the second bottle was put 75 per cent, into the third 50 per cent, and into the fourth 25 per cent as much as into the first bottle. These four bottles will be referred to as first, second, third, and fourth. The supplementary material was mixed with the alfalfa before packing, and as nearly as practicable the relative amount of material was kept uniform. While the material in the first bottle was very tightly packed, more so than is possible in the silo, the second corresponded to tight packing in the silo, and the third to rather loose packing. The alfalfa in the fourth bottle was much more loosely packed than would occur in the ordinary silo.

Alfalfa was used in three conditions; green, wilted, and wilted plus water. All alfalfa was cut in about one-tenth bloom. The wilting was so timed that about one-fourth of the moisture had evaporated. Only an

[1] The complete report will show that 48 additional bottles with air valves were put up, but results from these are omitted entirely from this paper.

approximation in this respect was practicable. Alfalfa in these three conditions was then put into the bottles without supplement, and with supplements consisting of ground sound corn, ground germinated corn, molasses, and rye. The corn was allowed to germinate until the sprouts were about ¼ inch long. The amount of water added to the alfalfa was calculated to be about one-half of that which had evaporated in wilting. The proportions of the various supplements used are given in Table II.

QUALITY OF SILAGE PRODUCED AND EFFECT OF VARIOUS SUPPLEMENTS

On the basis of considering 80 per cent or above good silage, Table I was prepared. From Table II it can be seen that most of those that were good graded 100, only a few being 80 or 90. These figures denote only a shade of deterioration.

TABLE I.—*Distribution of good and poor alfalfa silage in bottles*

Kind of alfalfa silage.	Total number.	Number good.	Number poor.	Per centage good.
Alfalfa alone:				
Fresh	44	30	14	68.2
Wilted	44	42	2	95.4
Wilted+water	44	41	3	93.0
Alfalfa+corn 10:1:				
Total	12	12	0	100.0
Fresh	4	4	0	100.0
Wilted	4	4	0	100.0
Wilted+water	4	4	0	100.0
Alfalfa+germinated corn 20:1:				
Total	12	12	0	100.0
Fresh	4	4	0	100.0
Wilted	4	4	0	100.0
Wilted+water	4	4	0	100.0
Alfalfa+germinated corn 40:1:				
Total	12	8	4	66.6
Fresh	4	0	4	0
Wilted	4	4	0	100.0
Wilted+water	4	4	0	100.0
Alfalfa+molasses 30:1:				
Total	12	8	4	66.6
Fresh	4	0	4	0
Wilted	4	4	0	100.0
Wilted+water	4	4	0	100.0
Alfalfa+rye 3:1:				
Total	12	12	0	100.0
Fresh	4	4	0	100.0
Wilted	4	4	0	100.0
Wilted+water	4	4	0	100.0
Alfalfa+no supplement:				
Total	12	11	1	91.7
Fresh	4	3	1	75.0
Wilted	4	4	0	100.0
Wilted+water	4	4	0	100.0
Alfalfa alone:				
Full pack	33	30	3	90.9
75 per cent pack	33	30	3	90.9
50 per cent pack	33	28	5	84.8
25 per cent pack	33	25	8	75.7
With corn 20:1:				
Total	12	9	3	75.0
Fresh	4	4	0	100.0
Wilted	4	2	2	50.0
Wilted+water	4	3	1	75.0
With germinated corn 30:1:				
Total	12	12	0	100.0
Fresh	4	4	0	100.0
Wilted	4	4	0	100.0
Wilted+water	4	4	0	100.0
With molasses 20:1:				
Total	12	12	0	100.0
Fresh	4	4	0	100.0
Wilted	4	4	0	100.0
Wilted+water	4	4	0	100.0
With molasses 40:1:				
Total	12	8	4	66.6
Fresh	4	0	4	0
Wilted	4	4	0	100.0
Wilted+water	4	4	0	100.0
With rye 6:1:				
Total	12	9	3	75.0
Fresh	4	3	1	75.0
Wilted	4	4	0	100.0
Wilted+water	4	2	2	50.0

From a detailed study of the figures in Table I the following conclusions can be drawn:

INFLUENCE OF WILTING.—When fresh alfalfa was used, the percentage of bottles which had good silage was 68.2; for wilted alfalfa the percentage was 95.4, and for wilted alfalfa plus water it was 93.0.

INFLUENCE OF TIGHTNESS OF PACKING.—With a full and a three-fourths pack the percentage of bottles which had good silage was 90.9, with half pack it was 84.8, and with one-fourth pack it was 75.7. The tightness of packing is an advantage, in that it makes exclusion of air and retention of carbon dioxid more certain. A detailed study of the chemical data obtained showed that favorable development of acid took place if air was kept out.

INFLUENCE OF SOUND CORN AS A SUPPLEMENT.—When the proportion of sound corn added to the alfalfa was 1 to 10, the percentage of bottles having good silage was 100 for the fresh, for the wilted, and for the wilted plus water. When the proportion of sound corn to alfalfa was 1 to 20, the percentage of all bottles having good silage was 75. When fresh alfalfa was used, the percentage was 100; with wilted alfalfa it was 50; and with wilted alfalfa plus water it was 75. The results from the proportion of 1 to 20 are so contradictory that no conclusions can be drawn. Sound corn in the proportion of 1 to 10 is very effective if air is kept out.

INFLUENCE OF GERMINATED CORN AS A SUPPLEMENT.—With the proportion of 1 to 20 the percentage of all bottles having good silage was in all cases 100 for the fresh, for the wilted, and for the wilted plus water. The same results were obtained with the proportion of 1 to 30. With the proportion of 1 to 40 the percentage of all bottles having good silage was 66.6. When fresh alfalfa was used, none were good. When wilted alfalfa or wilted alfalfa plus water was used, the percentage of good silage was 100. Germinated corn is more effective as a supplement than sound corn. If too small an amount is used, the chances of success with fresh alfalfa are no better than if none were used. Wilting is an advantage.

INFLUENCE OF MOLASSES AS A SUPPLEMENT.—With the proportion of 1 to 20 the percentage of all bottles having good silage was 100 for the fresh, for the wilted, and for the wilted plus water. With the proportions 1 to 30 and 1 to 40 the percentage of bottles having good silage was in all cases 100, except with the fresh alfalfa, where they were all bad. In general, it may be said that molasses as a supplement has the same effectiveness as germinated corn.

RYE AS A SUPPLEMENT.—With the proportion 1 to 3 the percentage of all bottles having good silage was in all cases 100. With the proportion 1 to 6 the percentage of all bottles having good silage was 75; with fresh alfalfa it was 75, with wilted alfalfa it was 100, and with wilted alfalfa plus water it was 50. In general, it may be said that rye as a supplement was very effective when the alfalfa was wilted. If fresh, the amount of moisture seems to be too large for the formation of good silage.[1]

[1] "Good silage" as used in this paragraph means that putrefactive odors were absent. The rye, however, imparts a strong, peculiar odor of its own, but this is different from the odors due to putrefactive decomposition.

PRIMARY CONDITIONS FOR MAKING ALFALFA SILAGE

This analysis of the figures presented leads to the conclusion that the primary conditions for making good alfalfa silage are exclusion of air and retention of carbon dioxid. The use of a supplement is necessary to insure success because it is not possible in practice to fulfill these conditions absolutely.

CHEMICAL COMPOSITION OF SILAGE FROM BOTTLES

Table II gives the figures for the chemical analysis of the silage put up in the 132 bottles in the spring of 1915. After judging the quality at the time of opening, the silage was analyzed for moisture, acidity, total nitrogen, and nitrogen in amino form as determined by the formol titration. The quality of the silage was expressed on a percentage basis. When the quality of the silage from the four bottles in a set (full, three-fourths, one-half, and one-fourth pack) graded 90 to 100, only the average figures from the analysis of the four bottles are given in the tables. It was found that the tightness of packing made comparatively little difference in the percentage amount of chemical change produced.

TABLE II.—*Chemical analysis of alfalfa silage in bottles*

MADE FROM FRESHLY CUT ALFALFA

Kind of alfalfa silage and bottle No.	Grade.	Moisture.	Acidity for 5 gm.	Amino nitrogen for 5 gm.	Acidity.	Amino nitrogen.	Total nitrogen.	Ratio of amino nitrogen to total nitrogen.
	Per cent.	*Per cent.*	*C. c.*	*C. c.*	*Per cent.*	*Per cent.*	*Per cent.*	
Alfalfa alone:								
1	[a] 100	76.86	19.0	14.0	1.710	0.196	0.641	1:3.26
2	100	75.45	18.0	14.2	1.701	.199	.682	1:3.43
3	100	79.90	17.0	13.9	1.526	.195	.551	1:2.83
4	0	82.80	13.4	17.8	1.206	.249	.306	1:1.23
Average of 1, 2, and 3	100	77.40	18.0	14.0	1.646	.197	.625	1:3.18
Alfalfa + sound corn 10:1, average	100	72.49	27.8	15.6	2.498	.218	.640	1:2.94
Alfalfa+sound corn 20:1, average	100	74.54	25.3	14.7	2.275	.206	.639	1:3.10
Alfalfa+germinated corn 20:1, average	100	74.65	32.5	15.0	2.927	.210	.708	1:3.37
Alfalfa+germinated corn 30:1, average	[b] 100	76.48	29.9	15.9	2.687	.218	.656	1:3.01
Alfalfa+germinated corn 40:1:								
21	50	77.75	15.9	21.9	1.431	.307	.543	1:1.77
22	50	77.85	18.6	22.2	1.674	.291	.508	1:1.75
23	60	80.10	18.2	22.6	1.638	.316	.393	1:1.24
24	40	79.20	17.5	25.0	1.575	.350	.478	1:1.37
Average of 21, 22, 23, 24	.....	78.73	17.6	22.9	1.580	.316	.481	1:1.52
Alfalfa+molasses 20:1, average	100	75.83	26.6	15.3	2.392	.214	.670	1:3.13

[a] In the groups where results are given on each bottle separately, the first one is full pack, the second 75 per cent, the third 50 per cent, and the fourth 25 per cent.

[b] The bottle with 25 per cent pack graded only 90.

TABLE II.—*Chemical analysis of alfalfa silage*—Continued

MADE FROM FRESHLY CUT ALFALFA—continued

Kind of alfalfa silage and bottle No.	Grade.	Moisture.	Acidity for 5 gm.	Amino nitrogen for 5 gm.	Acidity.	Amino nitrogen.	Total nitrogen.	Ratio of amino nitrogen to total nitrogen.
	Per cent.	*Per cent.*	*C. c.*	*C. c.*	*Per cent.*	*Per cent.*	*Per cent.*	
Alfalfa+molasses 30:1:								
29	40	80.40	13.4	22.5	1.202	.315	.398	1:1.27
30	40	79.95	12.6	22.4	1.134	.314	.401	1:1.29
31	50	79.95	13.2	21.3	1.188	.298	.412	1:1.38
32	70	80.00	19.1	17.7	1.719	.248	.554	1:2.23
Average of 29, 30, 31, 32	.....	80.08	14.6	21.0	1.411	.294	.441	1:1.50
Alfalfa+molasses 40:1:								
33	50	78.50	15.0	21.0	1.350	.294	.408	1:1.39
54	50	80.55	16.0	21.6	1.440	.302	.399	1:1.33
35	60	79.90	19.4	20.1	1.746	.281	.411	1:1.46
36	50	81.20	16.1	23.1	1.449	.323	.398	1:1.23
Average of 33, 34, 35, 36	.....	80.04	16.6	21.5	1.496	.300	.404	1:1.35
Alfalfa+rye 3:1, average	100	68.59	27.5	18.3	2.475	.255	.705	1:2.76
Alfalfa+rye 6:1:								
41	100	68.95	27.0	17.4	2.426	.244	.711	1:2.91
42	100	71.20	24.4	17.8	2.196	.249	.689	1:2.76
43	100	71.60	24.1	18.8	2.165	.263	5.23	1:1.99
44	25	74.00	12.5	22.6	1.121	.316	.554	1:1.75
Average of 41, 42, 43	.....	70.58	25.2	18.0	2.262	.252	.641	1:2.54

MADE FROM WILTED ALFALFA

Alfalfa alone, average	[a] 100	68.96	28.0	24.7	2.522	0.368	0.855	1:2.33
Alfalfa+sound corn 10:1, average	100	62.68	34.9	24.2	3.143	.339	.887	1:2.62
Alfalfa+sound corn 20:1:								
57	100	64.05	35.4	25.1	3.186	.383	.992	1:2.59
58	100	62.75	34.8	25.2	3.132	.286	1.028	1:3.60
59	50	68.00	19.5	33.5	1.751	.469	.717	1:1.53
60	25	69.80	14.3	30.0	1.287	.420	.691	1:1.64
Average of 57, 58	.....	63.40	35.1	25.2	3.159	.335	1.010	1:3.02
Alfalfa+germinated corn 20:1, average	100	60.14	35.8	29.5	3.222	.413	1.170	1:2.83
Alfalfa+germinated corn 30:1, average	[a] 100	60.5	36.2	29.5	3.265	.412	1.172	1:2.85
Alfalfa+germinated corn 40:1, average	[a] 100	58.01	35.6	28.7	3.206	.401	1.209	1:3.01
Alfalfa+molasses 20:1, average	[a] 100	61.58	37.4	25.9	3.370	.363	1.115	1:3.08
Alfalfa+molasses 30:1, average	100	60.26	36.9	26.0	3.328	.364	1.190	1:3.27
Alfalfa+molasses 40:1, average	100	60.66	35.0	23.9	3.148	.335	1.126	1:3.37
Alfalfa+rye 3:1, average	100	68.24	31.2	23.1	2.540	.323	.741	1:2.30
Alfalfa+rye 6:1, average	100	66.34	30.3	28.1	2.477	.392	.894	1:2.28

[a] The bottle with 25 per cent pack graded only 90 or 95.

TABLE II.—*Chemical analysis of alfalfa silage*—Continued

MADE FROM WILTED ALFALFA PLUS WATER

Kind of alfalfa silage and bottle No.	Grade.	Moisture.	Acidity for 5 gm.	Amino nitrogen for 5 gm.	Acidity.	Amino nitrogen.	Total nitrogen.	Ratio of amino nitrogen to total nitrogen.
	Per cent.	*Per cent.*	*C. c.*	*C. c.*	*Per cent.*	*Per cent.*	*Per cent.*	
Alfalfa+water, average	100	73.36	25.6	23.5	2.302	.329	.685	1:2.08
Alfalfa+water+sound corn 10:1, average	[a] 100	65.46	34.8	23.5	3.131	.329	.877	1:2.67
Alfalfa+water+sound corn 20:1:								
65	100	69.10	36.4	24.0	3.276	.336	.840	1:2.50
66	95	68.60	34.8	22.9	3.132	.321	.838	1:2.61
67	90	69.70	31.3	24.6	2.817	.344	.800	1:2.33
68	50	72.00	25.7	27.3	2.313	.382	.707	1:1.85
Average of 65, 66, 67	.....	69.13	34.2	23.8	3.075	.334	.826	1:2.47
Alfalfa+water+germinated corn 20:1, average	100	66.65	36.9	22.2	3.328	.312	.920	1:2.95
Alfalfa+water+germinated corn 30:1, average	100	66.74	35.9	24.6	3.242	.331	.962	1:2.91
Alfalfa+water+germinated corn 40:1, average	100	65.80	37.3	28.7	3.227	.401	1.014	1:2.52
Alfalfa+water+molasses 20:1, average	100	65.55	36.1	23.5	3.255	.329	.953	1:2.90
Alfalfa+water+molasses 30:1, average	100	66.41	35.9	23.2	3.244	.324	.903	1:2.79
Alfalfa+water+molasses 40:1, average	100	72.19	34.2	20.7	3.074	.290	.771	1:2.66
Alfalfa+water+rye 3:1, average	100	68.30	30.4	23.2	2.734	.324	.775	1:2.39
Alfalfa+water+rye 6:1:								
129	90	70.40	26.0	25.7	2.340	.360	.778	1:2.16
130	80	69.80	27.5	25.3	2.475	.354	.769	1:2.17
131	70	71.30	26.4	25.5	2.376	.357	.730	1:2.04
132	70	70.40	25.1	24.4	2.255	.342	.758	1:2.21
Average of 129, 130, 131, 132	.....	70.48	26.3	24.2	2.362	.343	.759	1:2.22

[a] The bottle with 25 per cent pack graded only 90.

MOISTURE CONTENT.—The moisture was determined by drying 100 gm. in a steam oven for 10 hours. As it is best to use the sample in its original condition without any previous preparation, a large sample is taken. Preliminary trials showed that 10 hours were a sufficient length of time to bring these samples to a fairly constant weight. It is practically impossible to get a constant weight because of the amount of lactic and acetic acids present. All samples were dried a second time, however, in order to check accidental errors. The bottles containing silage from fresh alfalfa had a higher moisture content than the bottles containing wilted alfalfa and wilted alfalfa plus water. The sets of four where all the bottles had bad silage had a higher moisture content than any other sets. In individual cases bad silage had no more moisture than that which was good, the moisture content being only one factor of several that may cause poor silage; but too high moisture content is undesirable. The difference

in moisture content between the silage from wilted alfalfa and from wilted alfalfa plus water is not as great as would be expected. This is no doubt due to the fact that during the first two weeks' fermentation moisture was lost because the stoppers could not be kept in place.

ACIDITY CONTENT.—Acidity was determined by the method of extracting in 50 per cent alcohol. Investigations made at this laboratory [1] had shown that the method of water extraction did not give as high a percentage of acidity as the extraction with alcohol. The method used was as follows: Two hundred gm. of carefully mixed silage are passed through the clover cutter and are then placed in a 2-quart Mason jar. For well-mixed alfalfa silage where only total acidity is to be determined half of this amount is sufficient. For mixed silage from a silo or for ordinary corn silage it is best to use this size of sample, as there is a sufficiency of extract for other determinations, such as volatile acids and nitrogen in amino form. To the silage in the Mason jar are added 500 c. c. of 95 per cent neutral alcohol. The advantage of this procedure is that when the determination can not be finished at once the alcohol will stop bacterial and enzymic action, and the sample can be kept as long as desired. The amount of water present in the sample, as known from the moisture determination, is calculated, and water equivalent to the difference between this and 500 c. c. is added to the jar, making the total quantity of liquid in contact with the silage 1,000 c. c. The jar is then placed on a shaking machine for about six hours, after which the contents are thrown on a 32 cm. folded filter. Triplicate portions of 25 c. c. of this filtrate are titrated with *N/20* sodium hydroxid, using phenolphthalein as the indicator.

The figures for acidity are probably large. The titration was made on a portion of extract representing 5 gm. This means that the analytical error in computing to percentage is multiplied 20 times. The extract is highly colored, and the end point is not easily read. To compensate for this, all the acidity titrations, as well as the formol titrations, were made by the same person during the last two years of work. This gives the figures greater comparative value.

The results for acidity titration are expressed as cubic centimeters of *N/20* sodium hydroxid for the extract from 5 gm. of silage, and also as percentages of lactic acid. This gives a higher percentage of acidity than the reality; but as only comparative values are needed here, this method of calculation is sufficiently accurate. Farther on attention will be called to the relative amount of volatile and nonvolatile acids in alfalfa silage made with various supplements. The results for acidity, as well as for moisture, total nitrogen, and amino nitrogen, were averaged for each set of four bottles; but only those of approximately equal quality on the basis of percentage grade were included in this average.

[1] SWANSON, C. O., CALVIN, J. W., and HUNGERFORD, Edwin. ACIDITY IN SILAGE; METHOD OF DETERMINATION. *In* Jour. Amer. Chem. Soc., v. 35, no. 4, p. 476–483. 1913.

The results from bottles having a grade above 90 should manifestly not be averaged with those having a percentage grade of 70 or less.

PERCENTAGE OF ACIDITY IN GOOD SILAGE.—With no supplement the percentage of acidity in silage made from fresh alfalfa was 1.646; from wilted alfalfa, 2.522; and from wilted alfalfa plus water, 2.302. With sound corn as a supplement, the average percentage of acidity in silage made from fresh alfalfa was 2.387; from wilted alfalfa, 3.151; and from wilted alfalfa plus water, 3.103. With germinated corn as a supplement, the average percentage of acidity from all bottles in silage made from fresh alfalfa was 2.807; from wilted alfalfa, 3.231, and from wilted alfalfa plus water 3.266. The smaller proportions of corn used show a tendency to produce smaller percentages of acidity. This is shown by the individual figures given in the tables. This statement holds for both sound and germinated corn.

With molasses as a supplement, the average percentage of acidity in silage made from fresh alfalfa was 2.392; from wilted alfalfa, 3.282 and from wilted alfalfa plus water 3.191. As with corn, the smaller amounts of molasses used produce a slightly smaller percentage of acidity.

With rye as a supplement, the average percentage of acidity in silage made from fresh alfalfa was 2.369; from wilted alfalfa, 2.509; from wilted alfalfa plus water, 2.548.

The silage from wilted alfalfa had in all cases a higher percentage of acidity than the silage made from fresh alfalfa. The increase due to wilting varies from about 15 per cent where germinated corn was used to about 50 per cent where no supplement was used. The addition of water to the wilted alfalfa had a slight tendency to reduce the acidity.

PERCENTAGE OF ACIDITY IN BAD SILAGE.—The percentage of acidity in bad silage varies so much that averages have little value. In general the poorest silage had the lowest percentage of acidity, many samples of very bad silage having an acidity value of about 0.5 per cent.

METHOD OF DETERMINING NITROGEN IN AMINO FORM.—The nitrogen in amino form was determined in the same solution used for the acidity determinations, using the formol-titration method according to Sörensen, as described by Jessen-Hansen.[1] The method adapted to this work on silage is as follows: To 25 c. c. of the neutralized alcoholic extract representing 5 gm. of silage, were added 25 c. c. of a neutral solution of dilute formaldehyde. In practice the determination of nitrogen in amino form is made on the same portion of solution as used for acidity. The formaldehyde solution was made by diluting one volume of 40 per cent commercial formaldehyde with one and one-half volumes of water, and making it neutral to phemolphthalein. After adding the formaldehyde, the solution was allowed to stand for 15 minutes, after which the titration was made to a rose-red. In a previous paper[2] attention has

[1] JESSEN-HANSEN, H. DIE FORMOLTITRATION. *In* ABDERHALDEN, Emil. HANDBUCH DER BIOCHEMISCHEN ARBEITSMETHODEN. Bd. 6, p. 262–277, fig. 53. Berlin, 1912.

[2] SWANSON, C. O., and TAGUE, E. L. A STUDY OF CERTAIN CONDITIONS WHICH AFFECT THE ACTIVITY OF PROTEOLYTIC ENZYMES IN WHEAT FLOUR. *In* Jour. Amer. Chem. Soc., v. 38, no. 5, p. 1098–1109. 1916.

been called to the fact that in some extracts like those from flour it is necessary to use thymolthalein. With the extracts from silage there was no difficulty in using phenolphthalein. In the same paper was also discussed the necessity of titrating to a rose-red instead of only to a pink.

The results are given in cubic centimeters of a *N/20* sodium hydroxid, neutralized by the extract representing a 5-gm. charge of silage, and also in percentage of amino nitrogen. This amino nitrogen was calculated on the assumption that 1 c. c. of a *N/20* sodium-hydroxid solution is equivalent to 0.7 mgm. of nitrogen. It is assumed that for every amino group fixed by the formaldehyde there is a corresponding carboxyl group set free. The correctness of this assumption depends, of course, on the nature of the nitrogenous compounds which take part in the reaction. As all these data are comparative, the assumptions made are sufficiently accurate for the present purpose.

PERCENTAGE OF NITROGEN IN AMINO FORM IN GOOD SILAGE.—For the sake of brevity this form of nitrogen will be called titrable nitrogen. The percentage of titrable nitrogen in silage made from fresh alfalfa averages nearly 0.2, and there is only a small amount of variation in the silage from the different bottles. The addition of supplements to fresh alfalfa has very little influence on the amount of titrable nitrogen produced, though the addition of a supplement has a tendency to increase the amount. The amount of titrable nitrogen in silage made from wilted alfalfa averages from one-third to twice that found in silage made from fresh alfalfa. The average percentage of titrable nitrogen with the various supplements to fresh alfalfa was as follows: Sound corn, 0.212; germinated corn, 0.214; molasses, 0.214; rye, 0.254. The average percentage of titrable nitrogen with the various supplements to wilted alfalfa was as follows: Sound corn, 0.337; germinated corn, 0.409; molasses, 0.354; rye, 0.358. In silage made from wilted alfalfa plus water the percentage of titrable nitrogen is notably lower than when water was not used. The percentages in wilted alfalfa plus water with the various supplements were as follows: Sound corn, 0.338; germinated corn, 0.348; molasses, 0.314; rye, 0.334. There is a remarkable uniformity in the amount of titrable nitrogen obtained from the different bottles. The addition of the supplements does not have nearly as much influence as wilting. The addition of water has a tendency to decrease the amount of titrable nitrogen formed.

PERCENTAGE OF NITROGEN IN AMINO FORM IN BAD SILAGE.—Under the same conditions of silage-making the percentage of titrable nitrogen in bad silage is only slightly greater than in good silage. However, the comparison must be limited to the alfalfa used in the same condition. The amount of titrable nitrogen in bad silage made from fresh alfalfa is not as large as the amount in good silage made from wilted alfalfa. The

increase in titrable nitrogen in bad silage as compared with the good is very slight, and in some cases is nil.

COMPARISON BETWEEN THE AMOUNT OF ACIDITY AND TITRABLE NITROGEN.—This comparative study can best be made by noting the number of cubic centimeters used in the acidity and in the formol titrations. In good silage the number of cubic centimeters used in the acidity titration is always greater than the quantity used in the formol titration, and the difference is greatest in the best silage. Where the acidity titration is equal to or less than the formol titration, the quality of the silage is poor. In the very bad silage the decrease in acidity is very large, while the increase in titrable nitrogen is comparatively small, if any. In bad silage it is not the increase in titrable nitrogen that is most notable, but the decrease in acidity. This decrease in acidity is due to molds using up the acids, and also to neutralization of acids by basic nitrogenous compounds. This latter will be discussed further.

RATIO OF TOTAL NITROGEN TO NITROGEN IN AMINO FORM.—The large amount of titrable nitrogen in relation to the total is remarkable. The ratio between titrable nitrogen and total nitrogen in good silage made from fresh alfalfa is 1 to 3+, and in good silage made from wilted alfalfa it is 1 to 2+. In bad silage the amount of titrable nitrogen is almost as large as the total. In the very bad silage nearly all the nitrogen is in this form. This is not due so much to the relative increase of titrable nitrogen as to loss of total. In the splitting of the protein there is an absolute loss of nitrogen. In this experiment there was no attempt to make a careful measurement of this loss; but to judge from the figures obtained, it amounts to about one-third to one-half of the total nitrogen in bad silage.

PART II.—EXPERIMENTS WITH THE ALFALFA SILAGE MADE IN 10-TON SILOS [1]

The seven silos were filled in the spring of 1915 about the time the first cutting of alfalfa was in one-tenth bloom. Corn chop, molasses, sweet-sorghum butts, and rye were used as supplements. The seven silos were filled as follows: No. 1, alfalfa alone; No. 2, alfalfa and molasses, 23 to 1; No. 3, alfalfa and molasses, 10 to 1; No. 4, alfalfa and corn chop, 9.6 to 1; No. 5, alfalfa and sweet-sorghum butts, 5.2 to 1; No. 6, alfalfa and rye, 2 to 1; No. 7, rye alone. The sweet-sorghum butts were of poor quality, and this accounts for the unsatisfactory results obtained; but, even as it was, the silage was of better quality than that obtained where rye was used as a supplement or when alfalfa was used alone. The palatability test made by the Dairy Department showed that the feeding quality of the silage produced ranged in the following order, beginning with the best: Alfalfa and molasses, 23 to 1; alfalfa and molasses, 10 to 1; alfalfa and corn chop, 9.6 to 1; alfalfa and sweet-sorghum butts, 5.2 to 1; alfalfa

[1] The work done in 1914 on this phase is omitted entirely from this paper.

and rye, 2 to 1; alfalfa alone; and rye alone. Alfalfa and corn, and alfalfa and molasses made satisfactory silage for dairy cows. The sweet-sorghum butts as a supplement would no doubt have made excellent silage if they had been first class. The rye proved unsatisfactory as a supplement.

In the center of each silo was placed a telescopic can holding from 25 to 50 pounds of material. The construction of these cans was such that the silage in the cans was subjected to the same pressure as the rest of the silage.[1] On opening it was found that the silage in each can was better than the silage next to the can in the silo. This proves that rigid exclusion of air is of prime necessity, but such rigid exclusion of air is not possible under practical conditions.

CHEMICAL ANALYSES

Samples for chemical analyses were taken by boring into the side of the silo with a 2-inch auger and then removing a core of silage with a 1¾-inch auger. The boring extended to about the center of the silo, and gave a sufficiently large sample for chemical work. This method of sampling is not satisfactory, though it is probably the best that can be used under such circumstances. This is especially true when the silage is made of a mixture of alfalfa and some supplement. Then, when the silage is partly spoiled in places, there is no certain way to ascertain whether an undue proportion of the bad silage is included in the sample. In addition to this, the leaves and stems differ very much in composition, and the right proportion of these is not always obtained. This difficulty in obtaining a satisfactory chemical sample should be considered when the chemical data are studied. But for this difficulty in sampling, the results would show more uniformity in variation.

The plan was to take samples from each silo every day after filling for the first seven days, every other day for the next week, then every four days for the next two weeks, then once a week, and finally once a month. The samples were prepared for analysis by passing them through a clover cutter whose feed was so regulated as to cut lengths ⅛ inch and less. This reduced the material to a satisfactory degree of fineness for all analyses made of the silage in the condition in which it came from the silo. The total nitrogen, as well as the complete feed analysis, was determined on the dried, finely ground samples. The following determinations were made on the fresh samples: Moisture, total acidity, sugar, and nitrogen in amino form as determined by the formol-titration method. These results are tabulated in Table III.

[1] These cans were designed by Prof. J. T. Willard about 25 years ago, while making silage experiments at that time.

TABLE III.—*Chemical changes in alfalfa silage in 10-ton silos*

SILO I (ALFALFA ALONE).

Period.	Moisture.	Total nitrogen.	Amino nitrogen.	Total acidity as lactic acid.	Sugar.
Days.		*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
0	62.75	1.02	0.0343	0.450	1.039
1	69.25	.91	.0532	.531	.765
2	69.00	.91	.0875	.621	.710
3	64.50	1.04	.1036	.797	.820
4	64.00	1.04	.1190	.936	.629
5	63.75	1.07	.1344	.963	None.
7	66.75	1.03	.1701	1.174	.300
9	63.85	1.04	.1358	1.062	.820
11	67.40	.90	.2338	1.714	None.
14	65.40	.96	.2527	1.629	.259
16	66.10	.73	.1708	1.476	.396
18	67.25	.52	.2394	1.633	None.
21	66.75	Lost.	.1673	1.279	.314
25	66.40	.89	.1813	1.152	.242
29	67.70	.87	.2338	1.845	None.
35	68.85	.84	.2800	1.431	.....
39	70.00	.64	.2176	1.183	.....
42	70.90	.75	.2415	1.260	.....
72	70.30	.75	.2590	1.935	.....
115	72.20	.61	.2030	1.674	.....
163	68.80	.79	.2485	1.562	.....
211	63.35	.96	.2180	1.728	.....
Can	69.95	.75	.2408	1.557	.....

SILO II (ALFALFA AND MOLASSES, 23 TO 1).

Period.	Moisture.	Total nitrogen.	Amino nitrogen.	Total acidity as lactic acid.	Sugar.
Days.		*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
0	70.83	0.76	0.0343	0.394	1.157
1	78.15	.52	.0658	.927	1.475
2	81.25	.49	.0466	.333	1.940
3	72.15	.75	.1078	.720	1.560
4	73.55	.64	.1008	1.724	.286
6	74.00	.66	.1575	1.886	.164
8	71.35	.71	.1708	2.446	None.
11	72.25	.71	.1624	2.403	.....
13	72.40	.70	.1834	2.443	.....
15	73.00	.68	.1701	2.470	.....
18	73.05	.66	.1568	2.241	.....
22	72.55	.56	.2065	2.538	.....
26	71.75	.75	.1904	2.808	.....
32	73.00	.71	.1932	2.443	.....
34	72.20	.74	.2170	2.448	.....
39	72.10	.74	.2114	2.704	.....
69	72.40	.71	.2100	2.444	.....
112	74.90	.65	.2506	2.452	.....
160	70.40	.73	.2296	2.241	.....
208	71.10	.79	.2814	2.898	.....
Can	74.60	.69	.2828	3.411	.....

SILO III (ALFALFA AND MOLASSES, 10 TO 1).

0	64.85	0.85	0.0294	0.389	.....
1	55.90	1.21	.1050	.702	0.589
2	61.35	.89	.1316	2.394	.900
3	58.45	.91	.1351	2.056	.600
5	61.80	.99	.1953	2.808	.410
7	59.00	1.03	.2212	2.808	.477
9	63.75	.86	.1736	3.015	.205
12	58.65	1.10	.2576	3.123	.273
14	62.40	.92	.1932	3.204	.437
17	63.00	.88	.1554	3.042	.714
21	61.30	.94	.2135	3.172	.442
25	61.50	.87	.1687	2.965	.321
29	65.40	.89	.1582	3.069	1.340
33	64.00	.85	.1806	3.024	None.
38	64.60	.86	.1764	3.172	.850
68	62.00	.87	.2408	2.813	None.
112	67.20	.82	.2436	3.745	.....
158	63.40	.94	.1470	3.348	.....
206	62.70	.88	.1988	3.556	.....
Can	70.40	.79	.2184	2.853	.....

SILO IV (ALFALFA AND CORN CHOP, 9.6 TO 1).

0	66.80	0.84	0.0406	0.378	0.900
1	66.35	.77	.0980	1.210	.123
2	69.60	.68	.1344	1.283	.164
3	67.15	.74	.1778	1.521	None.
5	65.00	.81	.2058	1.836	.....
7	66.15	.88	.2086	1.809	.....
10	67.40	.72	.2086	1.755	.....
12	66.40	.71	.2128	1.791	.....
15	66.60	.75	.2184	1.954	.....
19	65.50	.71	.2268	1.827	.....
23	67.20	.76	.2436	2.173	.....
27	68.30	.74	.2408	2.254	.....
31	67.80	.79	.2492	2.250	.....
36	66.70	.78	.2436	2.286	.....
66	68.10	.76	.2695	2.376	.....
110	69.50	.72	.3430	3.357	.....
156	65.50	.78	.2709	3.078	.....
204	66.70	.82	.2898	3.366	.....
Can	65.40	1.29	.3220	2.988	.....

SILO V (ALFALFA AND SWEET-SORGHUM BUTTS, 5.2 TO 1).

0	64.75	0.91	0.0350	0.387	0.696
1	67.40	.90	.0945	.618	.423
2	67.15	.87	.1540	.972	None.
3	66.50	.86	.1660	1.161	Do.
4	63.35	.77	.2142	1.584	.123
6	68.25	.76	.2562	1.273	None.
8	60.10	.89	.2506	1.768	.....
10	66.80	.81	.2520	1.521	.....
12	68.50	.73	.3038	1.498	.....
15	65.00	.81	.2926	1.728	.....
19	63.40	.88	.2870	1.949	.....
23	63.50	.84	.2961	1.890	.....
28	65.80	.83	.3388	1.759	.....
58	66.00	.84	.3136	1.913	.....
92	56.40	.81	.3325	2.412	.....
150	52.00	1.20	.3038	2.646	.....
198	57.65	.99	.3332	2.196	.....
Can	68.40	.65	.3780	1.485	.....

SILO VI (ALFALFA AND RYE, 2 TO 1).

0	63.25	0.96	0.0376	0.495	3.170
1	66.65	.83	.1127	.859	.629
2	66.60	.80	.1246	1.395	.368
3	69.75	.63	.1491	1.885	None.
5	66.25	.76	.1827	1.863	.....
7	66.75	.73	.2100	1.845	.....
9	69.60	.64	.2296	1.777	.....
11	65.75	.78	.2513	2.097	.....
14	68.50	.36	.2366	1.759	.....
18	62.25	.98	.3493	2.106	.....
22	68.90	.63	.2184	2.133	.....
27	69.80	.66	.2562	1.858	.....
57	69.40	.65	.2380	2.021	.....
91	72.40	.51	.3164	2.435	.....
150	64.80	Lost.	Lost.	1.971	.....
198	67.80	.75	.3129	2.502	.....
Can	61.05	1.00	.3724	2.646	.....

TABLE III.—*Chemical changes in alfalfa silage*—Continued

SILO VII (RYE ALONE).						SILO VII (RYE ALONE).					
Period.	Moisture.	Total nitrogen.	Amino nitrogen.	Total acidity as lactic acid.	Sugar.	Period.	Moisture.	Total nitrogen.	Amino nitrogen.	Total acidity as lactic acid.	Sugar.
Days.		*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*Days.*		*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
0.....	62.25	0.60	0.0350	0.450	1.87	18.....	63.55	.58	.1820	2.619	.....
1.....	64.25	.64	.0952	.680	1.69	22.....	63.90	.56	.1939	2.493	.....
2.....	57.50	.65	.1344	.756	1.64	27.....	61.70	.63	.2198	1.881	.....
3.....	60.40	.63	.1604	1.827	None.	57.....	65.60	.54	.1806	1.665	.....
5.....	59.55	Lost.	.1680	1.710	.83	91.....	67.50	.45	.2440	.774	.....
7.....	60.55	.62	.1764	1.683	.65	150.....	60.90	.63	.1743	2.313	.....
9.....	61.35	.60	.1715	1.584	.80	198.....	62.10	.63	.2352	1.958	.....
11.....	61.05	.65	.2016	2.475	.37	Can.....	57.70	.63	.2212	2.259	.....
14.....	64.10	.63	.1820	1.935	None.						

MOISTURE CONTENT.—The moisture content was highest in the silage made from alfalfa and molasses 20 to 1. In the others the moisture content was practically the same or a little lower than in silage made from well-matured corn or kafir. The moisture content depends on the amount of wilting before the alfalfa is put in the silo, and the moisture content of the supplement.

CONTENT OF TOTAL AND AMINO NITROGEN.—The nitrogen in amino form or titrable nitrogen was determined by the formal titration method, as described in the preceding pages. In all cases there was a sharp increase in the amount of titrable nitrogen in the material after it had been in the silo one day, as compared with the amount present before it was put into the silo. After the first day the increase in titrable nitrogen was gradual, up to the tenth or fourteenth day, when the maximum was reached. The amount fluctuated after this time, but this was probably due to variation in the samples. The silage made from sweet-sorghum butts had the largest amount of titrable nitrogen. The percentage amount of titrable nitrogen in the silage from these seven silos was approximately the same as in the silage made from fresh alfalfa put up in the bottles, but it was much less on the average than that made from wilted alfalfa put up in bottles. There was about the same ratio between total and titrable nitrogen that was found in the silage in the bottles—that is, nearly one-third of the total nitrogen was in the amino form.

TOTAL ACIDITY.—The total acidity was determined in the alcoholic extract as described in the preceding pages and the results calculated as lactic acid. The maximum amount of acidity was reached in approximately the following number of days: Alfalfa alone, 14 days; alfalfa and molasses 20 to 1, 8 days; alfalfa and molasses 10 to 1, 12 days; alfalfa and corn chop, 110 days; alfalfa and sweet-sorghum butts, 100 to 150 days; alfalfa and rye, 11 days; rye alone, 27 days. It should be noted that in those cases where the maximum was reached in the longer time a comparatively large amount of acidity was developed in about two weeks. Also, when the maximum acidity developed in the longer

time, the maximum was larger. This was not due to transfer of acid from above, as the acidity of the silage in the cans was in all cases very nearly the same as the maximum, and in some cases larger.

One function of the acid in silage is to furnish an environment unfavorable to putrefactive organisms. If easily fermentable carbohydrates such as are found in molasses or sweet-sorghum butts are present, the needed amount of acid will be developed through the action of beneficial organisms. The starch in corn is changed more slowly. In alfalfa alone the total amount of acidity produced is too small to bring about the desired condition. Furthermore, silos are not perfectly air-tight, like the bottles used in the preliminary work. Entrance of air makes it possible for putrefactive bacteria to grow.

SUGAR CONTENT.—Sugar was determined in the same alcoholic extract as was used in the acidity determination. The percentage of sugar varies among the different samples obtained from the same silo, but they all have this in common: In a few days to four weeks the sugar disappears. In corn, rye, and sweet-sorghum butts the sugar disappears in the shortest time. This must mean that the soluble carbohydrates are at once used in the production of acid. Where molasses was used in the largest amount, the sugar lasted the longest. More molasses than needed was used. In alfalfa alone the sugar also lasted long. This would appear to indicate that the conditions for transforming the carbohydrates in alfalfa into acids were not favorable.

VOLATILE ACIDS.—Volatile acids were determined according to the method of Dox and Neidig.[1] While the total acidity was calculated as lactic, the volatile acidity was calculated as acetic. By omitting the results for the first few days the following calculated averages were obtained for the total and volatile acidity:

Silage.	Total acidity.	Volatile acidity.
Alfalfa alone	1.483	1.038
Alfalfa + molasses, 20:1	2.413	.958
Alfalfa + molasses, 10:1	3.009	1.119
Alfalfa + corn chop, 10:1	2.242	1.229
Alfalfa + sweet-sorghum butts, 6:1	1.856	1.126
Alfalfa + rye, 2:1	1.975	.750
Rye alone	1.917	.569

Alfalfa alone produced the largest relative amount of volatile acidity. Rye produced a low amount. In the best silage the relative amount of volatile acid was about one-half of the percentage of total. The volatile acidity increased, but the rate of increase was not regular, nor does it seem to have any definite relation to changes in total acidity.[2]

[1] DOX, A. W., and NEIDIG, R. E. THE VOLATILE ALIPHATIC ACIDS OF CORN SILAGE. Iowa Agr. Exp. Sta. Research Bul. 7, 32 p. 1912.

[2] The cause for the relatively large figure for volatile acidity in alfalfa alone will be explained in the fuller report to be published.

SUMMARY

In this paper are presented the results of two series of experiments in making alfalfa silage. One was of preliminary nature, and milk bottles were used as silage containers, and in the other, 10-ton experimental silos were used. Conclusions presented in this paper are based on the results obtained from the bottles as well as from the experimental silos.

Alfalfa silage can be made from alfalfa alone if the containers insure absolute exclusion of air and retention of carbon dioxid. Such conditions are not practical of realization. The addition of supplements insures a more rapid and plentiful production of acids. These make conditions for putrefactive organisms unfavorable.

Wilted alfalfa is more suitable for making silage than the unwilted. The results show that the addition of water to unwilted alfalfa was harmful. Water added to wilted alfalfa gave no decisive results.

Molasses was the most effective supplement. Germinated corn, pound for pound, is more effective than sound corn as a supplement to alfalfa silage. Germinated corn produces results very similar to molasses. Rye would be suitable as a supplement but for the strong odor due to the rye.

Tightness of packing is a condition of success only in that it makes exclusion of air more certain.

Alfalfa silage contains a large amount of nitrogen in amino form. In good silage about one-third of the nitrogen is in this form, and in bad alfalfa silage the amount is sometimes one-half of the total nitrogen.

Most of the acids present in alfalfa silage are produced in the first two weeks. The percentage of acidity may increase after that, but the increase in comparatively slight.

The alfalfa as it is put into the silo contains only a small amount of nitrogen in amino form. Most of the change of nitrogen into amino form takes place in the first 10 days. Silage from wilted alfalfa contains more nitrogen in this form than that made from fresh alfalfa.

Sugar present in the materials used in making silage disappears very rapidly. Completely matured silage contains no sugar.

STUDIES ON OAT BREEDING—V: THE F_1 AND F_2 GENERATIONS ON A CROSS BETWEEN A NAKED AND A HULLED OAT[1]

By JACOB ZINN and FRANK M. SURFACE,
Maine Agricultural Experiment Station

INTRODUCTION

The present paper is an account of the results obtained from a cross between representatives of two subspecies, the naked oat, *Avena sativa nuda* var. *inermis* and *Avena sativa patula* var. Victor. These varieties possess several contrasting characters. An examination of the literature has failed to reveal any detailed descriptions of the inheritance of the naked and hulled characters in oats. Von Tschermak (9, p. 85; 10, p. 364)[2] states that in a cross between a naked variety, *Avena chinensis*, and a hulled oat the hull-less character is apparently dominant. The segregation resulted in naked forms, intermediate forms, and fully hulled oats. He also states that the multiflorous character of the naked oat is correllated with the naked character of the grain and that the character of firmly hulled grain excludes the multiflorous condition.

It seemed probable that a more detailed study of these and other characters would be of considerable interest. The present paper reports the results obtained as far as the second generation. The main characters dealt with in this article are the type of flowers and hulls and the characters of the glumes (pubescence, color, awning). This cross was made in 1914, and the progeny in both generations was grown out of doors. In the absence of the data on the third-generation plants, certain questions arising in the discussion could not be fully solved. The great variety of intermediate forms segregating in the second generation is responsible for the fact that a large part of this paper is descriptive. The more or less minute description of the parents and their progeny was also prompted by the desire to give a detailed picture of the forms involved, in order to facilitate the establishment of their botanical identity.

Regarding the methods used, the reader is referred to the paper recently published by one of the writers (6).

THE NAKED PARENT, AVENA SATIVA NUDA

The seed of the naked parent used in this cross was secured from the Russian Bureau of Acclimatization, having been originally grown in the Experimental Garden of the Horticultural School at Cholmy, Russia.

[1] Papers from the Biological Laboratory of the Maine Agricultural Experiment Station: No. 112.

[2] Reference is made by number to "Literature cited," p. 311-312.

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The hull-less seed was received under the name "*Avena chinensis*—China oat." However, the study of the plants grown from that seed in the breeding garden of this Station has led to the observation of some details which renders the correctness of the name under which the seed was received from Russia very doubtful. From the following description of the plant the conclusion seems justified that the variety in question is not *Avena sativa nuda* var. *chinensis*, but *Avena sativa nuda* var. *inermis* Kcke.

When grown in garden rows and under conditions prevailing in Maine, the plants attain an average height of about 130 cm. The stooling is medium, the average number of culms per plant being five. Plate 39, *A*, shows the general characters of the panicle. The head is about 30 cm. long. The ascending branches form a rather sharp angle with the main axis of the panicle, and give the head an oblong appearance.

The most interesting feature of this oat is the structure of its spikelets. While the number of kernels per spikelet in the common oat ranges from two to three, the spikelets of the naked oat are multiflorous, the number of flowers or kernels ranging from three to five. This feature appears in the most pronounced form at the tips of the whorls. Here, as a rule, the spikelets contain five flowers or kernels, while with those spikelets in the lower part of the whorl and also in the lower part of the panicle, as a whole, the number of flowers per spikelet is reduced so that in certain panicles the lowest whorls bear spikelets with only two to three flowers. Plate 40, *A*, shows a typical spikelet of a naked oat.

The long pedicels (rachis) of the individual flowers give the spikelet a raceme-like appearance. The length of the pedicels bearing the individual flowers varies considerably within the same spikelet, increasing from the uppermost flower towards the lowest one at the base of the spikelet. The relative length of the successive pedicels in a pentaflorous spikelet, from the uppermost down to the lowest, averages about 3.8, 6.0, 8.7, and 12.2 mm., respectively. The average length of the pedicels bearing the upper flower in an ordinary hulled oat averages about 2.5 mm., the shortest pedicels within a spikelet of a naked oat thus being still longer than the average length of the pedicel in the spikelet of the common oat.

It is of interest to note that the absolute length of the pedicels in the different spikelets of a panicle is also subject to variation. The uppermost spikelets of the main axis of the panicles, as well as the uppermost spikelets of each whorl, show the greatest absolute length of the pedicels, and consequently the longest spikelets. In the spikelets situated nearer the base of a whorl the pedicels have a tendency to be reduced in length. The same is true of the panicle as a whole. There is a gradual reduction of the absolute length of the pedicels and spikelets

toward the base of the panicle. Along with the reduction of the length of the pedicels, there occurs also a reduction of the number of flowers or kernels within the individual spikelets from the top of the main axis toward the base of the panicle. The same is true, but to a less extent, for each whorl. The tip spikelets of a given whorl are always the longest spikelets, and contain more flowers than any other spikelets in that whorl. Near the base of each whorl the spikelets show a marked reduction both in length and in number of flowers. This reduction of the number of kernels in the spikelets at the base of the whorl and of the panicle in conjunction with the shortening of the pedicels gives the spikelets in those regions of the head almost the appearance of those on a common hulled oat.

The reduction in the size and number of the spikelets which takes place gradually from the top to the base of the panicle and of each whorl recalls the well-known fact that the heaviest kernels in the oat panicle are borne near the top of the head and at the tips of the whorls. The lightest kernels are found at the base of the whorls and of the panicle, where sterility of the flowers quite often occurs. It is probable that the same physiological causes that favor the development of the grain in the uppermost regions of the common oat head account also for the larger number of flowers or kernels and for the greater length of the pedicels in the uppermost spikelets of the naked oat.

Another interesting feature of the spikelets of the naked oat is presented by the nature of the glumes. A multiflorous spikelet of the naked oat used in this cross bears at its base a pair of yellowish outer empty glumes, the glumæ proper, which cover the flowering glumes, or rather the paleæ. The lower flowering glume, or the palea inferior, is slightly longer than the corresponding outer sterile glume. The upper, inner glume, the palea superior, however, is much shorter, reaching only to about the middle of the palea inferior (Pl. 41, *B*). The length of the lower and upper flowering glume averages about 22.7 and 13.3 mm., respectively. This proportion between the size of the lower and upper flowering glume, characteristic of this naked oat, obtains also in the remaining flowers of the multiflorous spikelet. The outer flowering glume sometimes bears a very weak, straight awn. Whenever the awns are present, they are borne chiefly by the spikelets on the lower whorls. The rare occurrence and weak nature of the awns suggest that the strain used in this cross belongs to the variety *Avena nuda* var. *inermis*.

The structure of the lower flowering glume is very characteristic of the naked oat. As pointed out in another paper by one of the present writers (12), the lower flowering glume of the common oat represents a very strong protective organ of the flower and fruit of the Gramineae, being composed of four layers of cells, two layers of which, thickened and reenforced by a deposition of silicious matter and silicious cells, represent

the strong mechanical system of the lower flowering glume (Pl. 41, *A*). In the case of the naked oat there is no such differentiation of the cells of the lower flowering glume. As can be seen from Plate 41, *B*, the lower flowering glume is quite thin and membranous; it is also unusually wide and long. Its structure does not differ from that of the sterile outer glumes. This weak structure of the lower flowering glume of the naked oat, its unusually large dimensions in conjunction with the fact that it does not adhere to the caryopsis at all, gives to it the appearance of a sterile glume similar to the outer, empty glumes.

The color of the glumes is pale yellow. The caryopsis is slender and of light-yellow color (Pl. 42, *C*). The nakedness of the kernels, the multiflorous habit of the spikelets, the white color and absence of awns, are the main characters of the naked oat involved in the cross dealt with in this paper.

THE HULLED PARENT, AVENA SATIVA PATULA

The common hulled parent oat crossed with the naked oat is a pure line, known in our record books as line 262, and was selected from a variety known as the Victor. This variety is a black oat bred by a commercial seed company. According to its catalogue, this oat "was produced from six different parents, two of which were fall oats." Notwithstanding its hybrid origin, this variety in general and line 262 in particular breeds perfectly true in all characters. Line 262 was isolated in 1910 and has been grown every year since. A description of the Victor variety has been given by Surface and Barber (7). Line 262 was one used in the selection work carried on by Surface and Pearl (8).

The Victor oat is characterized by a tall straw. Its height in the garden averages about 155 cm. As seen in Plate 39, *A*, the head possesses a very long axis, long thin, drooping branches, covered with a moderate number of spikelets. Toward maturity the slender wavy branches yield to the weight of the grain, thus intensifying the drooping appearance of the head.

The grain of the Victor oat, as seen in Plate 46, *A*, is of medium size, the caryopsis being firmly inclosed by the flowering glumes. The color of the grain varies from dark brown to black. The lower grain bears a medium strong, kneed, and twisted dark-brown awn. The base of the grain is marked by a rather wide cleavage plane, similar almost to the base of the intermediate type resulting from a cross between a wild (*Avena fatua*) and a cultivated oat. On the majority of spikelets a few rather long hairs may be found at the sides of the base of the lower grain (Pl. 46, *A*). The main characters of the Victor oat contrasting with those of the naked oat are the hulled kernel, black color of grain, biflorous habit, the rather heavy awns, and the pubescence at the side of the base of the grain.

FIRST GENERATION

The first generation originated from a cross in which the naked oat was the male parent and the Victor oat the female. Eleven hybrid grains were obtained, seven of which failed to germinate when planted in the garden in 1915. The plants arising from the remaining four grains exhibited, on the whole, uniform characters, there being only a slight quantitative variation of the hull character. This point will be referred to below. Plate 39, *C*, gives the external appearance of the F_1 plants. By comparing this figure with figures *A* and *B* of Plate 39, it may be noted that the F_1 plants present an intermediate type between the two parents as to shape of head and form of spikelets. The longer head and the more widely spreading branches of the F_1 plants markedly contrast with the type of head of the naked oat and resemble rather the Victor parent, though the two types can be easily distinguished from each other.

With regard to the multiflorous characters, the F_1 plants show a prevalence, if not dominance, of this character over the common biflorous habit of the Victor oat. This observation agrees with the results obtained by Von Tschermak (9, p. 85; 10, p. 364) in a cross between the multiflorous oat *Avena sativa* var. *chinensis* and a common oat with normal flowers. While the habit of the spikelets of the F_1 plants is generally multiflorous, their form is different from that of the spikelets of the naked parent. This can be clearly seen by comparing figures *B* and *C* of Plate 39. The pedicels of the individual flowers within the spikelets of the F_1 plants are shorter than in the case of the naked parent, thus causing a shortening of the multiflorous spikelet. It was stated above in connection with the description of the naked oat that there is a tendency for the pedicels and for the flowers to be reduced in length and number, respectively, from the top of each whorl, and also from the top of the panicle as a whole toward the base. This tendency is still more pronounced in the F_1 plants. The longest multiflorous spikelets are grouped on the tips of the upper whorls and lead through gradual transitional forms to the biflorous spikelets present at the base of the whorls and of the panicle. It will be worth while bearing this feature in mind, as it is shown in a still more pronounced form in the intermediate types of F_2 plants and is correlated with gradual changes in the nature of the glumes.

With regard to the inheritance of the hull character—that is, the way in which the flowering glumes inclose the caryopsis—the F_1 plants represent an intermediate condition. Both parental forms, as well as the intermediate types of kernel described below, are present on the same panicle (Pl. 44, *A*). These intermediate forms are rather interesting, as they show naked kernels and firmly hulled ones side by side within

the same spikelet. Thus, spikelets occur in which the lower kernel is naked and the upper intermediately hulled. Another form is characterized by both lower and upper kernels being intermediately hulled. In still another type which occurs more frequently than either of the others the lower kernel is intermediately hulled and the upper completely hulled.

The intermediately hulled kernel is characterized by the following features: The caryopsis is inclosed by the lower flowering glume, which is for the most part membranous, hardening only along the median vascular bundle (Pl. 43, *C*). It is along this dorsal line that the glume adheres slightly to the caryopsis. The lateral edges of the glumes stand off freely, without embracing the caryopsis. The upper flowering glume lies closer to the caryopsis than in the case of the naked oat, but does not adhere to it.

All the types of hulls given above appear within the same panicle; in fact, often in the same whorl. As to the numerical distribution on the F_1 panicle of spikelets with different types of hulls, the spikelets with firmly hulled kernels and the naked ones occur in about the same numbers, while the intermediate types taken together exceed the total number of the former two groups. Since the intermediate types of spikelets are composed of both hulled and naked kernels, it may be said that the naked grain is prevalent over the hulled grain.

The local distribution of spikelets with varying types of hulls over the panicle is of some interest. As an illustration, the distribution of spikelets on one panicle may be presented here. All the spikelets of the head were examined, beginning from the top spikelet of the uppermost whorl downwards to its base. This order was maintained in the case of each whorl. The figures in Table I indicate, in numerical succession for each whorl, which of the successive spikelets, beginning with the uppermost, presented a given type of hull.

From this table the following points may be noted: The spikelets in which all the kernels are naked or in which the type of hulls most nearly approach that condition are grouped on the upper branches of each whorl. On the lower branches of each whorl the naked kernels gradually become replaced by transitional forms leading up to the perfectly hulled kernels at the base of the whorl. This is also true of the panicle as a whole. The uppermost whorl bears only spikelets with naked kernels. The next lower whorl already exhibits transitional forms characterized by the appearance of more or less intermediately hulled kernels. With the lowest whorl a condition is reached which is almost the opposite of the uppermost whorl.

If we compare this feature with the behavior of the multiflorous character in the F_1 plants, we can easily note an interdependence between the two characters. The multiflorous spikelets are similarly grouped about the top of the panicle and on the upper branches of each whorl,

reaching a biflorous condition at the base of the panicle and at the base of the whorls. The normal biflorous, or rarely triflorous, condition of the spikelet is completely correlated with the firmly hulled kernels. There is a negative correlation between the tetraflorus or pentaflorous condition of the spikelet and the firmly hulled kernels, as no multiflorous spikelets contain firmly hulled kernels. This negative correlation was also observed by Von Tschermak (9, p. 85; 10, p. 364) in his cross between a common oat and the multiflorous *Avena sativa* var. *chinensis*. It follows, then, that there is a correlation between the multiflorous character of spikelets and the hull-lessness of the kernels. This correlation, however, does not appear to be complete, as some cases were observed in the second-generation plants where naked kernels are borne by biflorous spikelets (Pl. 42, *A*).

TABLE I.—*Distribution of the different types of spikelets on the panicle in F_1 oat plants*

Whorl No.	Type of hulls of grain in individual spikelets.	Position of successive spikelets on whorl.
I	All kernels naked	1, 2, 3, 4, 5.
II	All kernels naked	1, 2, 3.
	All kernels intermediately hulled	4.
	Lowest kernel intermediately hulled; upper firmly hulled	5, 6.
III	Kernels intermediately hulled	1.
	Lowest kernel naked; upper firmly hulled	2, 3, 4, 6.
	Both kernels naked	5.
	Lowest kernel intermediately hulled; upper firmly hulled	7, 8, 9, 10, 11.
	All kernels hulled	12.
IV	All kernels naked	1, 2, 3.
	Lowest kernel intermediately hulled; upper firmly hulled	4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15.
	All kernels hulled	16, 17, 18, 19, 20.
V	All kernels intermediately hulled	1, 2.
	All kernels hulled	3, 4, 5.

Regarding the inheritance of the grain color, the F_1 plants show dominance of the black pigment, although the color of the grain is not so intense as the black color of the Victor parent. In connection with the distribution of the pigment it is of interest to note that in the case of a hull-less grain the lower membranous flowering glume shows no pigment whatever, being, as it is, in no connection with the grain. On such grain the pigment is confined to the upper flowering glume. In the same measure, however, as the lower flowering glume begins to grow coarser and adheres along the line of the median vascular bundle, the pigment appears along that line, spreading out from it over the remainder of the hull body with decreasing intensity.

The size of the kernel of the F_1 plants is intermediate between the two parents.

On the F_1 plants the awns are present only occasionally, being borne by the spikelets of the lower whorls. The awns are weak and straight, with no basal portion. The appearance of the awn, as will be seen more distinctly in the F_2 plants, is limited by the nature of the glume that bears it.

The character of pubescence appears in the F_1 plants more distinctly than with the Victor parent. The base of the firmly hulled and intermediately hulled kernels bears at its sides a fairly thick tuft of hairs. Since the pubescence on the grain of the Victor parent occurs only in the form of a few hairs, it would appear that the intensifying of the pubescence of the F_1 plants is possibly due to the influence of hybridization. The part which the other parent, *Avena nuda*, might possibly play in the augmentation of the pubescence can not be easily determined, as its kernels are naked, and, hence, offer no chance for the pubescence to develop. This point will be referred to later in connection with the discussions of the character of pubescence in the second-generation plants.

SECOND GENERATION

The four F_1 plants furnished seed enough to raise a considerable number of F_2 plants in 1916. The second generation comprised 854 plants, all of which were examined for the characters discussed above.

A.—HULL CHARACTER

With reference to the hull characters the F_2 segregation presents a variety of forms, among which at least six types can be distinguished. Two of these types represent the parental forms. Plate 43, *B*, shows the typical naked form from the F_2 generation. A comparison of this figure with figure *B* of Plate 39 shows a slight difference in the appearance of the two types, owing to the fact that in the naked forms from the F_2 generation the pedicels are often somewhat shortened, which causes the spikelets to appear more contracted than in the case of the naked parent. The multiflorous character of the naked forms of the F_2 generation is in several cases also modified in the direction of a reduction of the number of flowers per spikelet, pentaflorous spikelets being confined mainly to the top of the whorls, while the other spikelets contain only four or three flowers. This condition is very pronounced in some plants where the biflorous spikelets with naked kernels prevail over the multiflorous spikelets. A few plants were even found where, except for a few top spikelets with three or seldom four kernels all spikelets are biflorous, with two naked kernels per spikelet. These plants look much like a normal biflorous oat (Pl. 42, *A*). This is interesting to note, as it shows that the correlation between the multiflorous character and nakedness of the kernels is not complete.

The second F_2 type to be described contains the plants with fully hulled grain. This type is much simpler and more uniform than the

hull-less type discussed above. The biflorous condition of flowers is completely linked with firmly hulled kernals. In this respect the F_2 generation segregates a group of plants which reproduce the type of the Victor parent, as will be seen from Plate 43, *A*. The grain of this group, except for the rather heavy pubescence at the base of the grain, resembles very closely the type of grain of the Victor parent (Pl. 46, *B*).

Within the limits drawn by the above two groups of the parental type there is a rather wide range of intermediate forms marked by different gradations in regard to the hull character. Four types may be distinguished. Beginning with the group most nearly approaching the naked condition of grain, there is a form in which a few upper kernels in spikelets borne on the lowest whorl of the panicle are intermediately or firmly hulled, all the others being naked. The next form stands close to the former, but is marked by the presence of a few intermediately hulled lower kernels in the spikelets in the lower region of the panicle.

This form leads to the next type, which represents the largest group among the intermediate plants and shows all possible gradations between the naked and the hulled oat on the same panicle. Plate 45 shows a series of spikelets with the different gradations of the hull character, taken from a single oat head. The spikelets with the naked kernels are borne on the upper portions of the whorl. Next to these appear spikelets in which the lowest kernel is naked, and the upper ones are intermediately hulled. About the middle of the panicle spikelets prevail in which the lowest kernel is naked and the upper kernels firmly hulled. Below these, a condition is reached in which the lower kernel in the spikelet is intermediately hulled and the upper kernels are firmly hulled. Finally, at the base of the spikelet there are a few perfectly hulled kernels. It will be noted that this group of intermediate plants resembles the F_1 generation more closely than any other form.

The last group of the F_2 plants with intermediately hulled grain linking with the type of plants with firmly hulled grain shows a rather simple condition in which the tip spikelets are hull-less, the grain in the middle section of the panicle is intermediately hulled, while the lowest part of the panicle bears only completely hulled grain.

After the description of the F_2 forms as to type of hull, the inheritance of the hull character may now be discussed. As shown above, the first-generation plants are intermediate, showing the characters of both parents. The second generation segregates into two groups of the parental types and into a group of intermediate forms presenting a continuous series of different gradations. Whether these gradations within the group of intermediate forms are controlled by separate factors that will cause some of them to breed true or whether they are to be considered as a result of the heterozygous condition with only one pair of factors involved can not be determined at present. It is hoped that the data for the third generation will throw light on this

question. So far as the segregation in F_2 is concerned, it can be well explained by assuming one pair of genes. The heterozygous condition of these genes is represented by the intermediate plants, while the plants with typically hulled and typically naked grain represent the respective homozygous condition. From the detailed description of the intermediate plants it will be clear that neither gene is truly dominant. In general appearance the intermediate forms more nearly resemble the hull-less parent.

Table II shows a good agreement between the observed and the expected results. All the intermediate forms are here grouped in one class.

TABLE II.—*Segregation in regard to the hull character*

Item.	Hulled.	Intermediate.	Naked.
Observed	221	404	229
Expected	*213.5*	*426*	*213.5*

The inheritance of this character thus exhibits a Mendelian behavior, which is known as the Zea type, after Correns. This condition is analogous to that presented by the base of the lower grain in the cross between a wild and a cultivated oat (6) and by the character of awning in the cross between certain bearded and beardless wheats (1, p. 157–159; 3). The question whether the inheritance of the hull character of the present cross will follow the pure Zea type or the intermediate modification of that type established by Von Tschermak (9, p. 85; 10, p. 364), for the hull character of barley can not be solved until the data for the third generation are available.

B.—GRAIN COLOR

The segregation in regard to the grain color presents a simple Mendelian ratio. As already stated, the F_1 plants show a dominance of the pigment, even though it does not possess the intensity of the color of the Victor grain. In the second generation there is also a group of plants showing a light-brown color of the grain, but the intensity of the pigment grades from the light-brown color over brown to dark brown and black when a condition similar to that of the black parent is reached. Grouping all plants with pigmented grain into one class, we obtain the following ratio:

Observed ..... Black : White = 646 : 208.
Expected ..... Black : White = 640.5 : 213.5.

As will be noted, the observed results agree very well with the expected on a monohybrid ratio.

It will next be of interest to determine whether there is a relation between the factors controlling the hull character and the color genes. In Table III all the intermediately hulled forms are grouped in one class.

TABLE III.—*Relation between the hull character and the grain color*

Item.	Hulled.		Intermediate.		Hull-less.	
	Black.	White.	Black.	White.	Black.	White.
Observed	166	55	296	108	184	45
Expected	*160. 1*	*53. 4*	*320. 3*	*106. 8*	*160. 1*	*53. 4*
Ratio	*3*	*1*	*6*	*2*	*3*	*1*

From this table it is evident that the observed numbers agree fairly well with the expected and show that the genes for the hull character and grain color segregate independently. As mentioned earlier, the intermediate forms show a greater resemblance to the hull-less oats than to the hulled forms. If the plants with intermediate and hull-less grain are grouped together, a still better agreement between the observed and expected numbers is obtained. This is shown in the Table IV, where the expected numbers are calculated on the 9 : 3 : 3 : 1 ratio.

TABLE IV.—*Relation between the hull character and the grain color*

Item.	Black.		White.	
	Hull-less.	Hulled.	Hull-less.	Hulled.
Observed	480	166	153	55
Expected	*480. 3*	*160. 1*	*160. 1*	*53. 4*

C.—PUBESCENCE AT THE BASE OF THE GRAIN

Another character involved in this cross is the pubescence at the base of the grain. The conditions in regard to this character are somewhat complicated by the nature of the naked parent. The character of the pubescence can only be established for the hulled Victor parent and for the hulled progeny, while it is obvious that in the case of the naked parent and all the naked forms of the segregating progeny the manifestation of that character is impossible. Moreover, there is evidence that also in the majority of the intermediate forms of the second generation the total or partial nakedness of the lower kernels interferes with the normal manifestation of the pubescence. This causes a deviation from the expected type of pubescence, which will be discussed below. In grouping the intermediate forms of F_2 in regard to pubescence it is often difficult to decide whether a given plant does not carry the factor for pubescence at the base of the grain or whether its manifestation is only foiled by the fact that the grain is not inclosed in the firm glumes.

In studying the inheritance of this character it may be well to consider first the plants in which the hull character does not interfere with

the free expression of the genes for pubescence at the base of the lower grain if present. In the present data there are 323 F_2 plants which fulfill these conditions. They include all the plants with completely hulled grain and those intermediate forms which most closely approach this condition. Of these plants 300 are pubescent and 23 are smooth (Pl. 42, *B*). These numbers indicate a bifactorial character. Calculating the expected number of plants on the 15-to-1 ratio, we have the results shown in Table V.

TABLE V.—*Segregation with reference to the pubescence at the base of the lower grain*

Item.	Pubescent.	Smooth.
Observed number	300	23
Expected number	*302.8*	*20.2*
Ratio	*15*	*1*

The agreement here is very good.

It should not be forgotten, however, that these results are obtained from a selected population. In such a case there is always the danger that, through linkage or for other reasons, the selected group may not represent the condition in the whole population. However, a consideration of all the forms of the second generation that have an opportunity for the expression of the genes for pubescence furnishes evidence that the group of plants discussed above does represent a random sample of the F_2 population. Of the whole F_2 population 229 plants have completely naked grain. It is obvious that these plants must be excluded from a consideration of the character of pubescence. Of the remaining 625 plants, 369 are pubescent at the base of the lower grain, 128 are pubescent at the base of both lower and upper grain, 81 are pubescent at the base of the upper grain only, and 47 are smooth. The group of 81 plants pubescent only at the base of the upper grain presents a very interesting condition which is the result of the interference of the nakedness or seminakedness of the lower grain with the manifestation of the pubescence at its base.

While this case will be more fully discussed in connection with the discussion of the pubescence of the upper grain, it may suffice here to state that in all the 81 plants the lower grain was totally or partly naked, and that this condition obviously prevented the development of pubescence at the base of the lower grain. This circumstance, coupled with the fact that heretofore not a single case has been reported of an oat, cultivated or wild, with the lower grain smooth and the upper pubescent, justifies the conclusion that the 81 plants might have developed the pubescence at the base of the lower grain if it were not for its naked or

seminaked condition. Including, then, these plants in the group of plants with pubescence at the base of the lower grain, we obtain the ratio of 578 pubescent to 47 smooth. The expectation on a 15-to-1 ratio is 586.5 to 39.1. The agreement between the observed and expected numbers is fairly good and bears out the conclusion regarding the bifactorial character for pubescence found above for the selected group of completely and almost completely hulled forms. This group then appears to represent a random sample of the F_2 population in respect to pubescence. To avoid the disturbing influence of the naked or seminaked condition, only this group of completely or almost completely hulled forms will be considered in the further discussion.

It will next be of interest to see whether there is any relation between the genes for pubescence at the base of the lower grain and the color genes. Of the 323 plants to be considered, 236 are black and 87 white. This is a very close approximation to the expected 3-to-1 ratio, and shows that in respect to grain color this selected group of plants is representative of the complete F_2 generation.

If there is no linkage between either of the factors for pubescence and the color genes, the expected ratio will be 45 black pubescent to 3 black smooth, to 15 white pubescent to 1 white smooth. The expected numbers calculated from this ratio, together with the observed number of plants in each class, are shown in Table VI.

TABLE VI.—*Relation of the color genes and the genes for pubescence at base of the lower grain*

Item.	Black.		White.	
	Pubescent.	Smooth.	Pubescent.	Smooth.
Observed number	226	10	74	13
Expected number	*227.1*	*15.1*	*75.7*	*5.1*
Ratio	*45*	*3*	*15*	*1*

This is a very reasonable agreement between the observed and expected numbers. These results show that the color genes segregate independently of the two genes for pubescence.

As shown in Plate 46, *A*, the pubescence on the Victor oat is quite long, in fact much longer than the hairs found at the base of most cultivated oats. Nilsson-Ehle (4) has stated that the long and short pubescence at the base of the grain segregates in a monohybrid ratio. This is found to be the case in the present cross. Out of the 300 pubescent plants 217 have long pubescence and 83 short. This is undoubtedly a 3-to-1 ratio.

Furthermore, the genes for long and short pubescence segregate independently of the color genes, as shown in Table VII.

TABLE VII.—*Relation of the color genes and the length of pubescence*

Item.	Black.		White.	
	Long.	Short.	Long.	Short.
Observed number	172	55	44	29
Expected number	*165.3*	*55.1*	*55.1*	*18.7*
Ratio	*9*	*3*	*3*	*1*

On returning to the question of the presence and absence of pubescence at the base of the lower grain, several interesting features may be noted. As already stated, the grain of the Victor parent shows a few long hairs at the base of the lower grain. In the first generation this pubescence is intensified, and in the second generation many plants show thick, long tufts at the side of the base. The difference in the pubescence of the grain of the parent plant and these second-generation plants can easily be seen by comparing figures *A* and *B* of Plate 46.

The F_2 generation thus presents an augmentation of the pubescence. The pubescence appears here not only intensified but also as a dihybrid character. The mere intensifying of the pubescence may conceivably be due to the stimulating influence of hybridization. It is further possible that the augmentation of the pubescence and its dihybrid character is accounted for by the hulled Victor parents' bearing latent characters which through hybridization become activated and released.

A more plausible and simple explanation of the bifactorial character of the pubescence in the second generation is suggested by the assumption of a second gene for pubescence entering from the naked parent. The question whether the naked parent contributed a gene for pubescence in the hybrid progeny can not be solved directly, since, owing to the nakedness of the grain, the manifestation of a possible inherent gene for pubescence is prevented. However, the evidence obtained in other crosses between the hulled Victor oat used in the present cross and other hulled strains tends to indicate that the pubescence of the Victor oat is a monohybrid character. This evidence then speaks in favor of the assumption in the present cross of a gene for pubescence in the naked parent.

A still more remarkable feature of this cross is the presence of a pubescence of a distinct type at the base of the upper grain in the hybrid plants (Pl. 46, *B;* 47). While several cultivated oat varieties have been observed which possess a pubescence of varying strength at the base of the lower grain, only three cases are recorded in the literature in which a few individual spikelets developed pubescence also at the base of the upper grain. Thus, Christie (2) records a case of two Danish varieties developing a pubescence at the base of the upper grain. Nilsson-Ehle (5) found that certain plants which he regards as atavistic regressions

toward the wild-oat parent showed a pubescence on the upper grain. These atavistic regressions represent really the wild form. In similar cases observed occasionally by the present writers the pubescence appears not in form of tufts of hair at either side of the base, but covers the whole base as in the wild oat. Finally, Fruwirth (2) observed two spikelets of an oat plant in which also the upper grain had a pubescence. This character, however, did not prove to be heritable, as the progeny of that plant did not develop it.

In many wild oats, *Avena fatua*, *A. sterilis*, etc., a heavy pubescence is developed at the base of the upper grain. In *A. fatua* that condition appears completely correlated with other specific characters (11, 6). The type of pubescence in the present case, however, is different from that of the upper grain in the wild oat. While in the latter case a heavy, thick pubescence covers all sides of the base (6, pl. 3, fig. 6) the pubescence developed at the base of the upper grain in hybrid plants of the cross in question shows only two more or less thick tufts of hair at either side of the base. As seen in Plate 46, *C*, this type of pubescence is similar to that of the intermediate forms resulting from crosses between *A. fatua* and cultivated oats.

In order to determine the distribution of the plants with pubescence on the upper grain in relation to the character of the glume, the plants were grouped in three classes. The first class comprises the plants with typically intermediate type of hull—that is, plants with a majority of intermediately hulled lower grain and a few fully hulled. The middle group represents the forms most closely approaching the hulled condition of grain, while the third class contains only the plants with normal, firmly hulled grain. Table VIII shows these three classes of plants in relation to the pubescence on the upper grain.

TABLE VIII.—*Relation between the pubescence on upper grain and the hull character*

Character of hull.....	Intermediate.		Intermediate, with prevalence of hulled grain.		Hulled.	
Upper grain.....	Pubescent.	Smooth.	Pubescent.	Smooth.	Pubescent.	Smooth.
	176	136	33	59	0	221

This table shows that the majority of plants with pubescence on the upper grain fall into the group in which the lower grain is either naked or intermediately hulled and the upper intermediately or firmly hulled. In the same measure as the glume of the lower grain becomes coarser approaching, as in the middle group, the firmly hulled condition, the pubescence on the upper grain tends to disappear.

In the last group with normal, completely hulled grain none of the upper grain develops a pubescence at the base. This gradual change in

the manifestation of the pubescence can be observed on the same panicle, even on the same whorl, in an intermediate form. The top spikelets in this case are usually naked, no manifestation of the pubescence being possible. In the succeeding spikelets the lower grain may be naked and the upper intermediately or firmly hulled, the pubescence, if the gene for it is present, appearing at the base of the upper grain. Eighty-one plants presenting this condition were observed. In the spikelets located still lower on the whorl or panicle the glume of the lower spikelets become coarser, adheres more closely to the caryopsis, in which condition the pubescence appears already on the lower grain and decreases on the upper; finally, the firmly hulled normal condition of the lower grain causes the complete disappearance of the pubescence on the upper grain. Thus, a single panicle or even whorl presents gradual changes in the local manifestation of pubescence, following the changes in the type of hull.

This fact, as well as the evidence obtained from other crosses between the Victor line and common hulled-oat varieties in which no case of an upper grain being pubescent was observed, make it evident that the development of pubescence at the base of the upper grain in the progeny of the present cross is caused by the naked or seminaked condition of the lower grain. Obviously, this naked or seminaked condition of the lower grain causes a disturbance in the normal manifestation of the pubescence, and it seems as though the gene for pubescence, suppressed or restrained in its appearance in the normal region, tends to manifest itself at the base of the upper grain, this latter thus taking the part of the lower grain.

The examination of plants relative to the presence and absence of pubescence at the base of the upper grain does not indicate a simple Mendelian behavior. There are 209 plants with pubescent upper grain and 416 plants with smooth upper grain. The expected numbers are, on a 3-to-1 ratio, 156 pubescent to 469 smooth, the difference between the observed and expected numbers being 53. This difference is five times larger than the standard deviation ($\sqrt{n\,p\,q} = 10.8$) and is probably beyond the range of fluctuation of random sampling.

The development of pubescence at the base of the upper grain in this cross is then plainly the result of the modifications caused by the naked parent. The same cause also accounts for the abnormal behavior of the 81 plants which develop a pubescence at the base of the upper grain while the lower grain is smooth. Already a casual inspection shows that, since in all the 81 plants the lower grain is naked or seminaked, the expression of the gene for pubescence is prevented. This is borne out by the fact that when the lower grain is completely hulled, as in the last group of Table VIII—thus giving full opportunity for developing the pubescence—none of the upper grains are pubescent. No single case has been recorded in the literature of an oat with a smooth lower grain and pubescent upper grain. As already pointed out, only certain wild oats normally develop a pubescence on the upper grain, but even here the development

of that pubescence is controlled by the pubescence of the lower grain and, as Surface (6) showed for the cross between wild and cultivated oats—

in the absence of the gene for pubescence on the lower grain the gene for pubesence on the upper is unable to act.

D.—INHERITANCE OF AWNS

The inheritance of the awn character remains to be discussed. The behavior of this character, like the pubescence discussed above, is closely associated with the morphological constitution of the lower flowering glumes and is affected by the same disturbances caused by the naked parent. As already stated, the strength of the lower flowering glume in the intermediate forms may vary on the same panicle, or even whorl, from a thin membraneous condition to the coarseness and strength of the normal hull. These variations of the glume are accompanied by corresponding variations in the strength of the awn. The naked forms and the naked spikelets of the intermediate forms bear only a very weak, thin awn, often appearing as a tender prolongation of the median, vascular bundle at or near the tip of the glume. The group of intermediate forms approaching the firmly hulled forms have partly a weak awn and partly a medium strong awn, with a distinct twisted, basal portion. The third group, including only plants with firmly hulled grain, possesses a strong kneed and twisted awn along with medium strong awns. Table IX shows these three groups of plants in relation to the three classes of awns.

TABLE IX.—*Relation of the hull character to the strength of the awn*

Hull character	Naked and intermediate, prevalence of naked.			Intermediate, hulled grain prevalent.			Hulled grain.		
Kind of awn	Weak.	Medium strong.	Strong.	Weak.	Medium strong.	Strong.	Weak.	Medium strong.	Strong.
Number	438	35	4	50	44	8	27	132	61
Percentage	*92.5*	*6.6*	*0.8*	*49.1*	*43.1*	*7.8*	*12*	*60*	*28*

The relation between the kind of awn and character of hull is very evident. In the naked and seminaked group practically all awns are weak. In the middle group approaching the firmly hulled type of grain, the weak awns on one hand and the medium and strong awns on the other occur in approximately equal numbers. In the third class a condition opposite to that of the first group is reached, where 88 per cent of the plants have medium strong and strong awns. It may be stated that the same tendency also prevails in regard to the quantitative distribution of the awns, the lowest number of awned spikelets being correlated with the weakest kind of awn and, conversely, plants with strong awns having usually all spikelets awned.

From the above discussion it is obvious that the quality and quantity of awns is limited in this cross by the morphological constitution of the lower flowering glume, which in turn is determined by the gene for nakedness. In studying the inheritance of the awns, just as in the case of the pubescence, it is necessary to disregard those plants with naked or almost naked grain. On these naked plants there is no opportunity for the somatic expression of strong awns, even if the gene for such awns is present.

In Table IX the two classes of plants included under the rubrics "Intermediate hulled grain prevalent" and "Hulled grain" may be classified accurately with reference to awn characters. On combining these two classes of plants there are in all 322 plants, of which 77 have weak awns and 245 have medium strong or strong awns. This is apparently a 1-to-3 ratio, the expected numbers being 80 to 241.5. However, again this result is based upon a selected group of F_2 plants, and it is possible that this group is not a random sample of the F_2 population with respect to awn characters.

SUMMARY

This paper contains a description of the F_1 and F_2 generations of a cross between a black hulled oat, *Avena sativa patula* var. Victor, and a white naked oat, *Avena sativa nuda* var. *inermis*.

The hulled parent is characterized by the presence of firm flowering glumes (paleæ) which adhere closely to the caryopsis, biflorous spikelets, black color of the glumes, strong awns, and a long but rather sparse pubescence at the sides of the base of the lower grain.

The naked parent is characterized by the presence of loose membranous flowering glumes which do not adhere to the caryopsis, multiflorous spikelets, white or light yellow glume color, almost total absence of awns and the absence of pubescence. It is possible that the absence of awns and of pubescence is due to the inability of these characters to express themselves on the thin membranous glumes.

The F_1 generation is distinctly intermediate in most characters. In regard to the glumes, both naked and firmly hulled grain as well as intermediate forms are found on the same panicle and even in the same spikelet. As shown in Table I, the spikelets near the top of the panicle are either entirely naked or nearly so, while those spikelets near the base of the panicle tend to be firmly hulled. A similar but less marked relation is to be observed between the spikelets at the tip and base of each whorl.

In the F_2 generation a large number of intermediate forms appear. In addition to the two parental hull types, four intermediate classes were distinguished. These intermediate forms contain all gradations from the plants with perfectly hulled grain to the perfectly naked forms.

As shown in Table II, the inheritance of the hull characters presents a simple Mendelian relation giving 1 hulled, 2 intermediate, 1 naked. Likewise, in respect to grain color, there are 3 black plants to 1 white in the second generation.

As shown in Tables III and IV, the genes for these two characters segregate independently of each other.

In all cases multiflorous spikelets occur only in connection with naked grain. Plants with completely hulled grain bear only biflorous spikelets.

The inheritance of the pubescence at the base of the lower grain presents some difficulties, since this character can not manifest itself on plants with naked grain. By using a selected group of plants having hulled and intermediate grain it is found that this pubescence behaves as a bifactorial character, giving 15 pubescent plants to 1 without pubescence (Table V). Neither of these genes are linked with the color genes.

The evidence available indicates that one of these pubescent genes may come from the naked parent.

The presence of long and short pubescence at the base of the grain behaves as a monohybrid character and segregates independently of the other genes considered.

A remarkable feature of this cross is the presence of pubescence at the base of the upper or second grain. There are no cultivated varieties of oats which possess this character. In the present cross these forms occur only on spikelets where the lower grain is naked or seminaked. It is probable that the presence of this pubescence at the base of the upper grain is due to physiological disturbances caused by the presence of the naked lower grain.

The presence of awns is also affected by the nature of the glumes. All naked grains bear only a thin, weak awn. On considering only the hulled and intermediate types of grain, there appears to be a simple 3-to-1 ratio between plants with medium strong to strong awns and those plants with weak awns.

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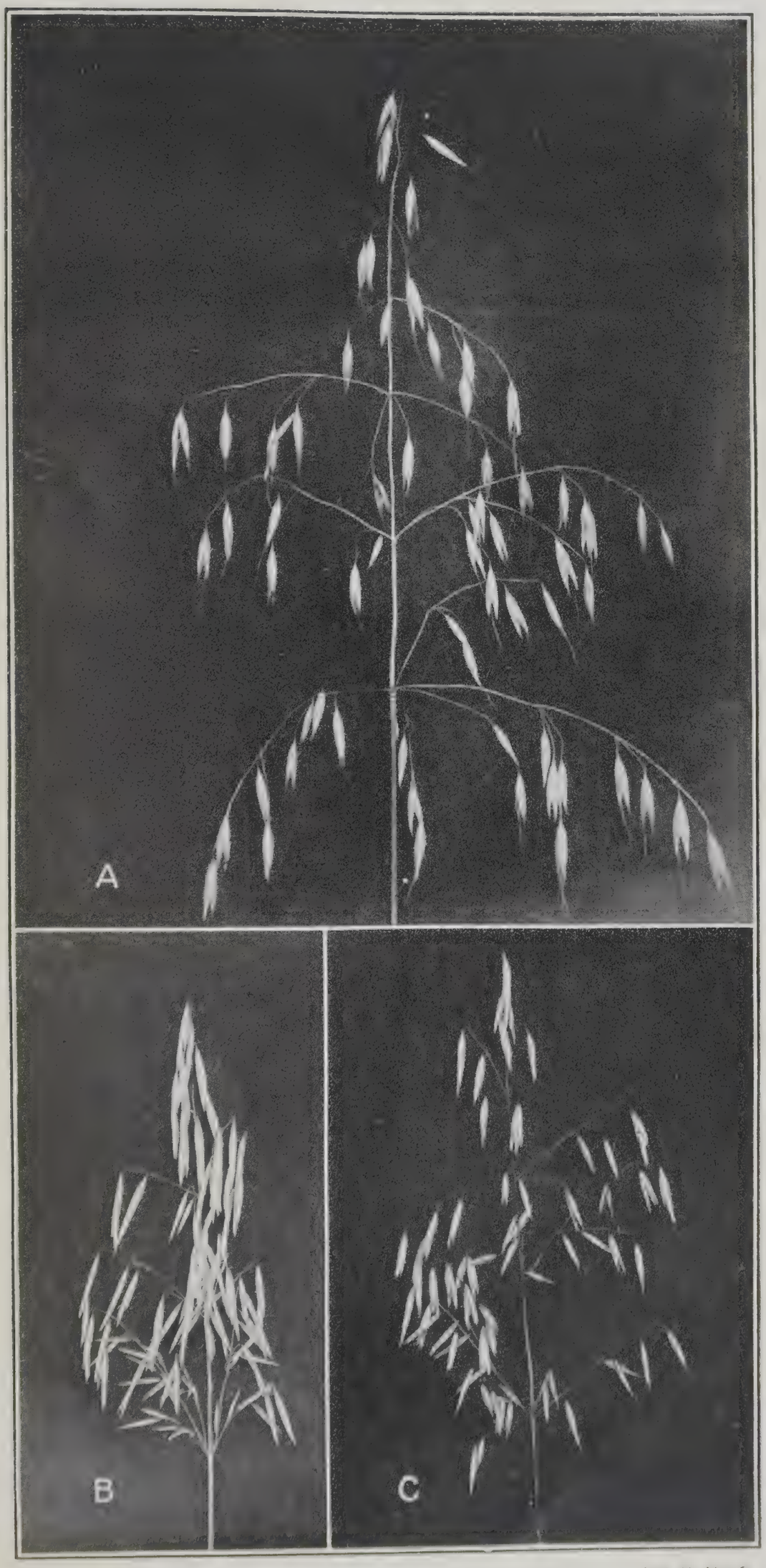
PLATE 39

A.—A head of the Victor oat, line 262. × 1/5.
B.—A head of the naked oat, *Avena sativa nuda* var. *inermis*. × 1/5.
C.—A head of an F_1 generation plant of the cross ♀ Victor × ♂ *Avena nuda*. × 1/5.


A
B
C

A
B

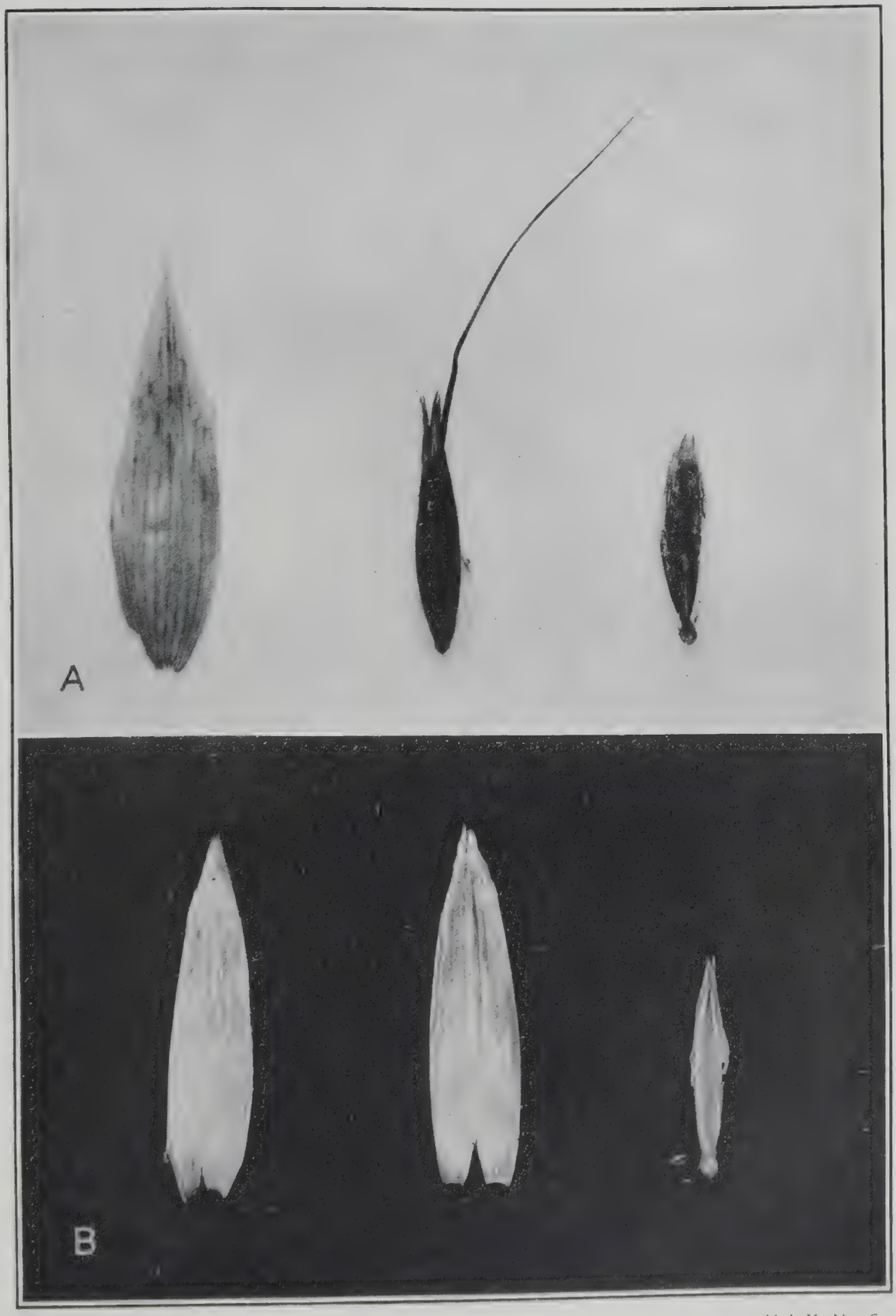
PLATE 40

A.—Single spikelet of *Avena nuda*. × 2.
B.—Single spikelet of the Victor oat. × 2.

PLATE 41

A.—Glumes of the Victor oat: From left to right—One of the outer, sterile, covering glumes, or the gluma; lower flowering glume, the palea inferior, and upper flowering glume, the palea superior. × 2.

B.—Glumes of the naked oat: From left to right—One of the glumæ, palea inferior, and palea superior. × 2.


A
B

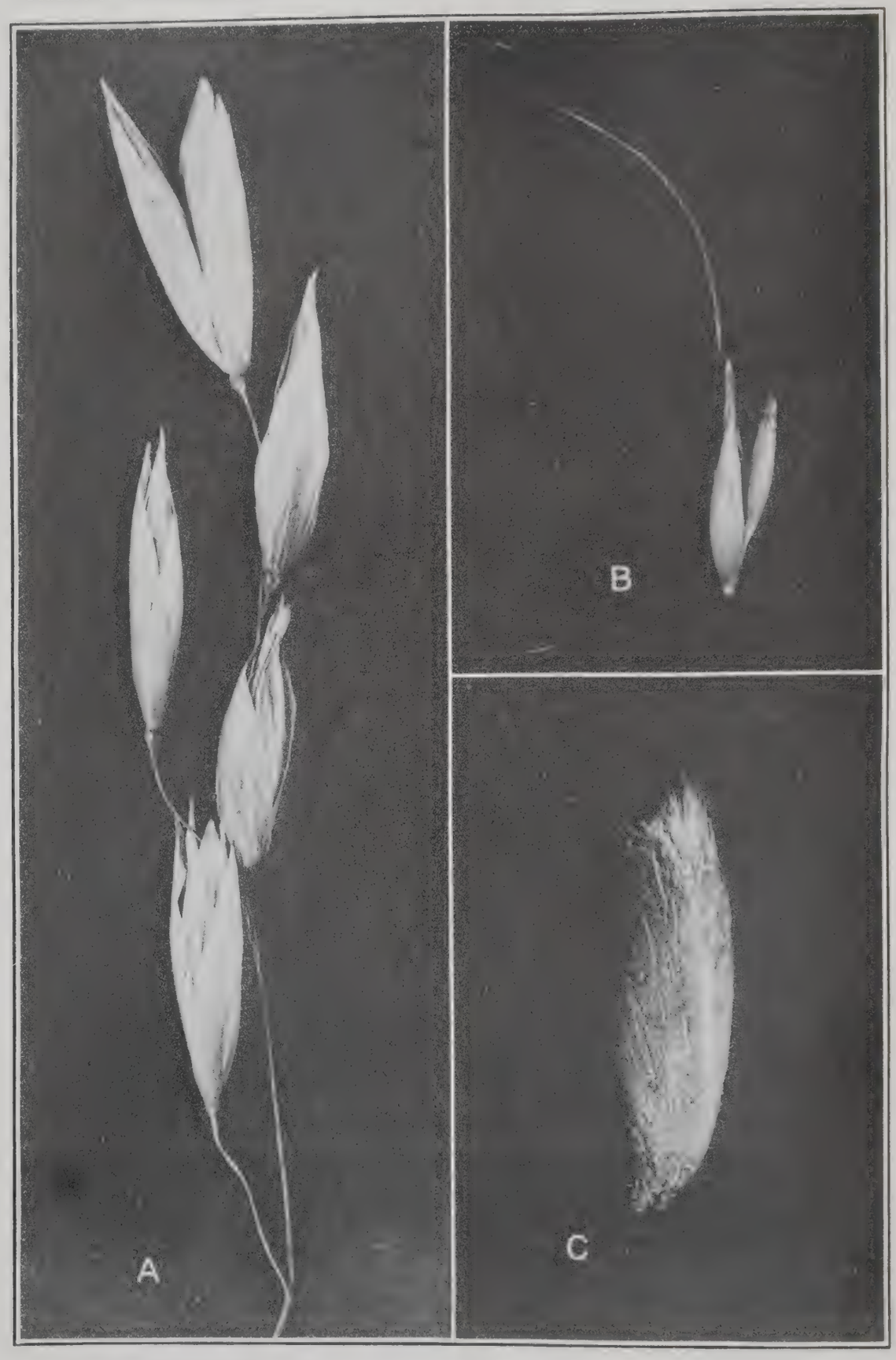

A
B
C

PLATE 42

A.—♀ Victor × ♂ *Avena nuda* F_2: A branch of a plant bearing biflorous spikelets containing naked kernels. × 2.

B.—♀ Victor × ♂ *Avena nuda* F_2: A white grain showing no pubescence at the base of the lower grain. × 2.

C.—Caryopsis of *Avena nuda*. × 5.

PLATE 43

A.—♀ Victor × ♂ *Avena nuda:* A head of an F_2 plant bearing only completely hulled grain. × 1/5.

B.—♀ Victor × ♂ *Avena nuda:* A head of an F_2 plant bearing only hull-less grain. × 1/5.

C.—♀ Victor × ♂ *Avena nuda* F_2: *a*, Spikelet with intermediately hulled grain; *b*, dorsal view of same. × 2.

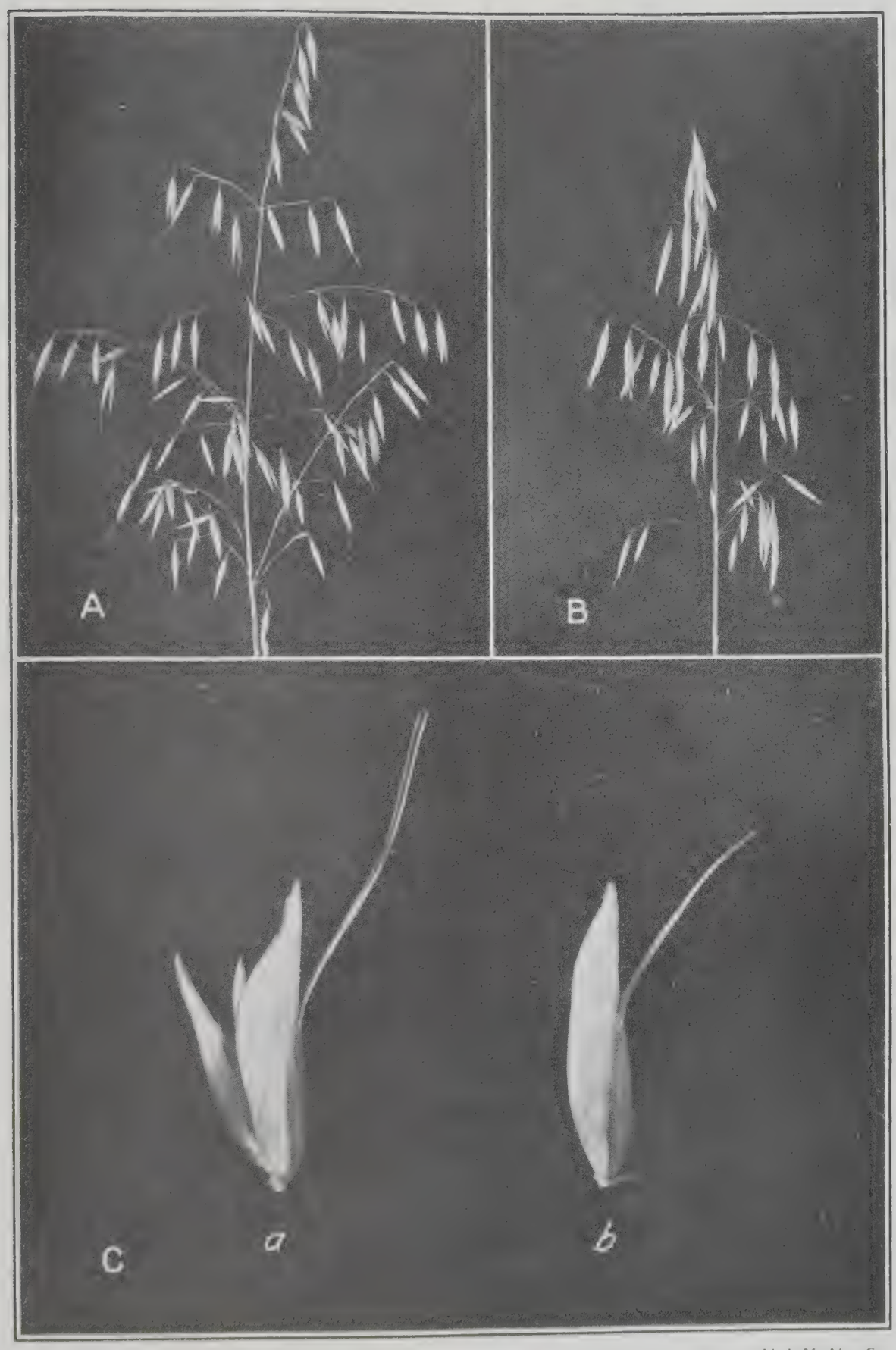

A
B
C
a
b

PLATE 44

♀ Victor × ♂ *Avena nuda* F_1: Types of grain. From left to right—Multiflorous spikelet bearing naked grain, intermediately hulled grain, and completely hulled grain. × 2.

PLATE 45

♀ Victor × ♂ *Avena nuda* F_2: Types of grain segregating in the second generation. From left to right—Multiflorous spikelet bearing naked grain, spikelet bearing naked grain and showing reduction in number of florets, intermediately hulled grain and completely hulled grain. × 2.

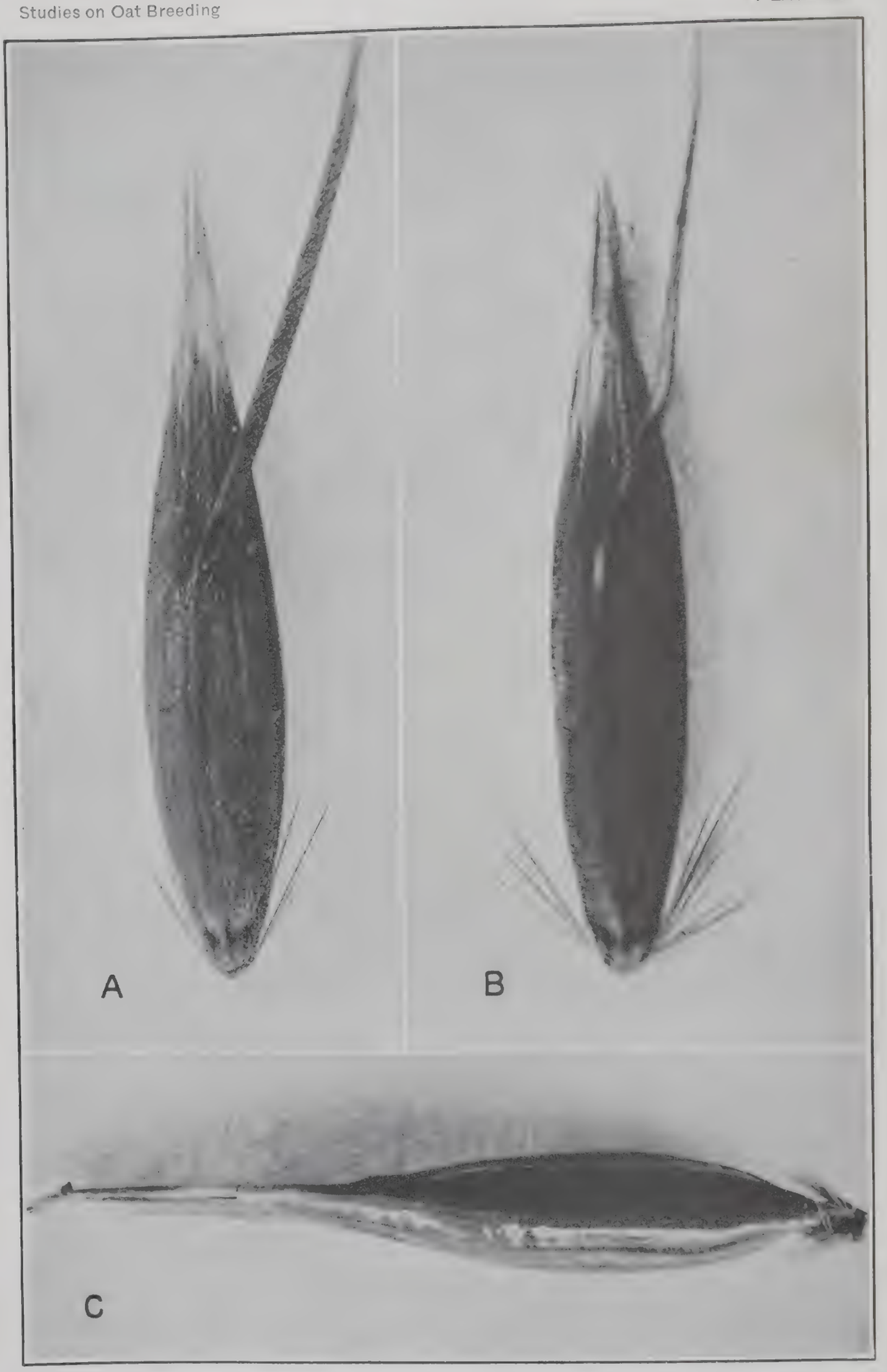

A
B
C

PLATE 46

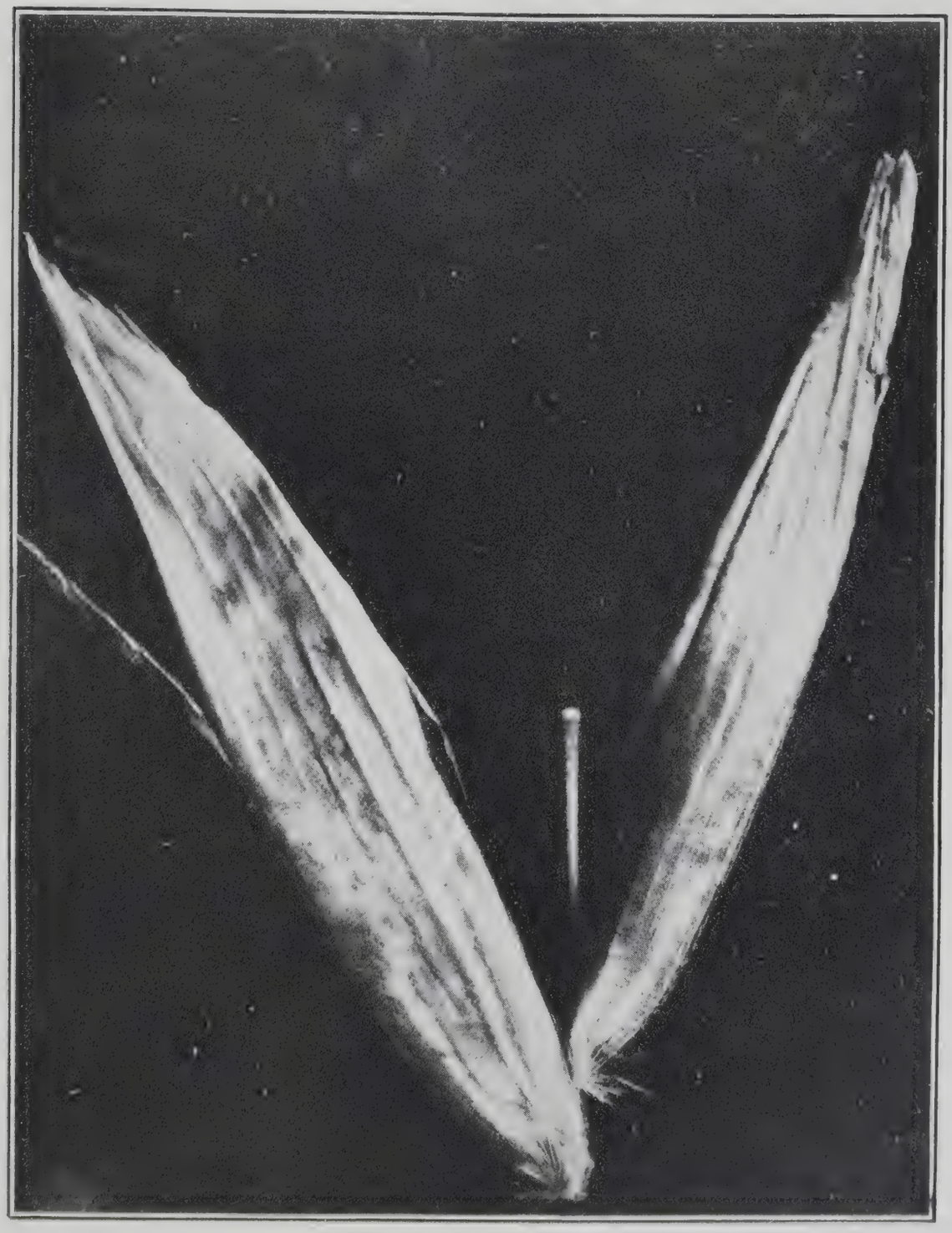
A.—Lower grain of the Victor oat showing the long but sparse pubescence at the sides of the base. × 5.

B.—♀ Victor × ♂ *Avena nuda* F_2: Lower grain showing a rather thick pubescence at the sides of the base. × 5.

C.—♀ Victor × ♂ *Avena nuda* F_2: Dorsal view of upper grain showing pubescence at the sides of the base. × 5.

PLATE 47

♀ Victor × ♂ *Avena nuda* F_2: A spiklet showing pubescence on both lower and upper grain. ×5.



TWO NEW CAMBIUM MINERS (DIPTERA)

By CHARLES T. GREENE,

Specialist on Forest Diptera, Forest Insect Investigations, Bureau of Entomology, United States Department of Agriculture

HISTORICAL REVIEW

The two species of Agromyza discussed in this paper add two new cambium miners to science. The larvæ mine in the cambium of the living tree, the mine leaving a scar known as a "pith-ray fleck." [1] The mines are very much like those of *Agromyza pruinosa* Coq., the cambium miner in river birch (*Betula nigra*).[2] One of the species was reared from red maple (*Acer rubrum*) and the other from service berry, or shadbush (*Amelanchier canadensis*). Both of these species run to *A. setosa* in the table of Agromyza by Malloch.[3]

A dipterous cambium miner was first reared in Europe in 1906 by Nielsen,[4] and in 1913 the author reared an American species.[2] Later, in 1915, another species was reared by Grossenbacher [5] which was redescribed by Malloch the same year.[6]

CHARACTER OF TREES ATTACKED

The trees attacked are apparently healthy, and infested ones can not be detected by their outward appearance. The only way to detect the larva is to remove the bark and expose the cambium, where at a glance one can generally recognize the new galleries from the old ones, since the new larval mines are only faintly darker than the living cambium, whereas all the old work is generally brown.

CAMBIUM MINER IN RED MAPLE

DESCRIPTION

ADULT

Agromyza aceris, n. sp.

MALE AND FEMALE.—Black; frons opaque black, reddish along upper edge of lunule; width of frons about one-half that of head; orbits wide; four orbital bristles present, situated near inner edge of orbit; shiny around base of orbitals, a row of microscopic hairs between eye margin and orbitals; ocellar triangle slightly indicated

[1] BROWN, H. P. PITH-RAY FLECKS IN WOOD. U. S. Dept. Agr. Forest Serv. Circ. 215, 15 p., 6 pl. 1913. References, p. 14–15.

[2] GREENE, C. T. THE CAMBIUM MINER IN RIVER BIRCH. *In* Jour. Agr. Research, v. 1, no. 6, p. 471–474, pl. 60–61. 1914.

[3] MALLOCH, J. R. A REVISION OF THE SPECIES OF AGROMYZA FALLEN, AND CERODONTHA RONDANI. (DIPTERA.) *In* Ann. Ent. Soc. Amer., v. 6, no. 3, p. 269–340, pl. 28–31. 1913.

[4] NIELSEN, J. C. ZOOLOGISCHE STUDIEN ÜBER DIE MARKFLECKE. *In* Zool. Jahrb., Abt. System., Geogr. u. Biol. Tiere, Bd. 23, Heft 6, p. 725–738, pl. 30. 1906.

[5] GROSSENBACHER, J. G. MEDULLARY SPOTS AND THEIR CAUSE. *In* Bul. Torrey Bot. Club, v. 42, no. 4, p. 227–239, pl. 10–11. 1915.

[6] MALLOCH, J. R. SOME ADDITIONAL RECORDS OF CHIRONOMIDÆ FOR ILLINOIS AND NOTES ON OTHER ILLINOIS DIPTERA. *In* Bul. Ill. State Lab. Nat. Hist., v. 11, art. 4, p. 349–350, pl. 84, fig. 8–11. 1915.

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THE CAMBIUM MINER IN SERVICE BERRY

DESCRIPTION

THE ADULT

Agromyza amelanchieris, n. sp.[1]

MALE AND FEMALE.—This species closely resembles *Agromyza aceris*, but is easily separated from it by its smaller size and the following differences: Black, slightly more opaque on the frons and thorax. Frons faintly depressed in the center, half as wide as head; red area above lunule wide; orbits fairly wide; five orbital bristles; microscopic hair present; ocellar triangle with longer black hairs; area between lunule and base of antennæ narrower and paler yellow; first and second joints of antennæ dull, dark reddish brown; third joint rounded, dull black, inner basal corner reddish; arista black, only slightly longer than upper orbital bristles; face opaque black, keel indistinct; facial depression with a very faint reddish reflection on each side; narrow red area on each side of face wanting; along upper part of oral margin narrower, reddish yellow; dorsum of thorax nearly opaque; abdomen blacker and more shining than thorax; hypopygium of male entirely black; legs, knees, and trochanters black; wings hyalin, veins nearly black; outer cross vein its own length from inner cross vein.

Length, male and female, 3 to 3.5 mm.

TYPE LOCALITY.—French Creek, W. Va. Mr. F. E. Brooks, collector.

TYPE.—Female, Cat. No. 21063, United States National Museum.

ALLOTYPE.—Male.

Described from seven specimens.

THE LARVA

The larva (Pl. 48, *C*) is quite similar to that of *Agromyza aceris*, except for the following differences: It is longer and more slender; the cephalopharyngeal skeleton is longer and not so robust; the anterior and posterior pairs of spiracles are slightly smaller; and the small chitinous plates on the sides, below the middle of the last segment, are arranged in four rows instead of three.

For further details see Plate 48, *C*.

Length, 20 to 25 mm.; diameter, 0.65 to 0.85 mm.

THE PUPA

The pupa (Pl. 48, *D*) is paler yellow and very much more pointed than that of *Agromyza aceris*. The grooves along the segmental lines are not so pronounced. The cephalic end of the pupal case is missing. The posterior spiracles are reddish, not quite so prominent and a little more elongated on the apex, plainly showing the three circular plates with the dorsal slit. The anal depression is reddish in the center. Otherwise it is like *A. aceris*, although very slightly smaller.

SEASONAL HISTORY

During June and the early part of July the larvæ were collected at French Creek. W. Va. They were nearly full grown and were taken from the trunk near the ground and from the roots. According to Mr. F. E. Brooks, who discovered them, "the larvæ leave a threadlike reddish line in the cambium." Nearly full-grown larvæ were collected at French Creek from June 10 to July 6, 1915. The time of pupation

[1] Submitted to the writer for study through the courtesy of Dr. A. L. Quaintance, Entomologist in Charge of Deciduous Fruit Insect Investigations, Bureau of Entomology.

stem is black, cylindrical, and the end is very faintly dented where it articulates with the anterior portion. From the posterior end of this stem are two long, flat, chitinous blades which are much longer than broad. They are dark brown above and black on the lower edge where they are slightly more chitinized. The muscles appear to be attached to the inside surface of these blades. On the underside, where the two large blades branch out from the stem, is a fingerlike projection, pointing backward. This projection is hollow and U-shaped and is divided at the apex. It is brownish above and black on the underside. For further details see Plate 48, *A*, *a*.

Along the upper front edge of the first segment next to the head there are small, impressed, parallel lines and the lower portion is covered with numerous, very short, yellowish brown spines. On the dorsum of this segment, just in front of the middle, are located the anterior spiracles; they are T-shaped, yellow and very faintly raised above the surface. From a dorsal view they have about 8 or 10 microscopic ringlets around the edge, giving the edges a scalloped appearance. Back of these spiracles is a faint depression formed by a transverse fold or wrinkle. The segmental lines are rather weak and the segmentation can be plainly seen on the plate. Along the basal segmental line of the last segment are three rows of microscopic, yellow, chitinous plates; the first row (toward the head) is broken on the dorsum only, the middle one is broken on the dorsum and venter while the third row is just a short row on each side. Just below the middle of the last segment are three short rows of the same plates on each side of the larva. The posterior spiracles are situated on two tubercles located on the dorsal, apical portion of the last segment. These tubercles are pale yellow and flattened along the apex. On this apical edge are three brown, nearly round, chitinous plates, each having a transverse dorsal slit. For details see Plate 48, *A*, *b*. On the ventral side near the apex is a large tubercle with the anal opening located on the apex.

Average length, 15 to 17 mm.; average diameter, 0.75 to 1 mm.

PUPA

The pupa (Pl. 48, *B*) is pale yellow, cylindrical, and tapers very slightly toward each end. It is faintly shiny and is formed by the shrinkage of the larva. The head is entirely retracted, leaving 11 segments plainly visible. All segments are marked with well-defined grooves. The entire surface of the pupal case is faintly marked with transverse striæ. All the segments are nearly uniform in width except those on each end, which are narrower. The place where the head was retracted is marked by a small puckered surface, faintly reddish. The anterior and posterior pairs of spiracles are formed by the shrinkage of those of the larva into small reddish brown, chitinous tubercles. The anal area is marked by a circular depression which is nearly black in the center. The adult emerges through a slit made along the lateral edge of the first three or four segments.

Length of male, 4 mm.; diameter, 1.65 mm. Length of female, 5 mm.; diameter, 2 mm.

SEASONAL HISTORY

During July and August the larvæ were fairly common at Falls Church, Va., and the surrounding country. They mine down the cambium in the trunk and roots of *Acer rubrum*, and, after reaching maturity, make their exit, pupating in the ground about ½ to 1 inch to the side of the exit hole. Full-grown larvæ were collected from July 10 to August 19 by Mr. T. E. Snyder and the writer. Full-grown larvæ were also taken at French Creek, West Virginia, on July 11, 1916, by Mr. F. E. Brooks.

Pupation took place from July 10 until the latter part of August, and the species remained in the pupa stage during the winter.

Adults emerged from April 24 to 26, 1916.

and covered with numerous short black hairs; ocelli pale yellow; ocellar bristles large and directed obliquely forward; below lunule to base of antennæ dull clay yellow; first joint of antennæ clay-yellow, second and third joints dull reddish brown, second joint with a light reflection on upper edge and the third joint rounded, only slightly wider than long, blackish on upper edge; arista nearly black, thickened at base, brownish above thickened portion; pubescence of antennæ indistinct; arista nearly twice as long as upper orbital bristle; center of face opaque black, keel indistinct, a narrow area on each side of face, extending from base of antennæ to cheeks, dull dark red; opaque black of frons extending down around eye in a narrow area; across lower part of face, along oral margin, an arcuate, dull clay-yellow band with the pointed ends extending down along the oral margin (narrower in female); ridge along sides of oral margin black; vibrissæ distinct; cheeks dull black; proboscis and palpi black, palpi with several bristles; dorsum of thorax black, subshining, with a faint grayish appearance and thickly covered with bristly hairs; four dorsocentrals; the pair of bristles between last pair of dorsocentrals about three-fourths as large as the latter; pleura concolorous; scutellum bare, concolorous, with two pairs of marginal macrochætæ, apical pair decussate; stem of halteres yellowish brown, knobs nearly white; abdomen concolorous, covered with numerous hairs; marginal bristles distinct; hypopygium of male dull yellowish brown, darker toward apex; legs black, knees and trochanters yellowish; middle tibiæ bearing several distinct bristles on posterior side near middle; wings hyalin, veins yellowish brown, costal vein and apex of first vein dark brown; costal vein reaching fourth vein; first costal division about three-fourths as long as second; inner cross vein slightly before apex of first vein; outer cross vein slightly more than its own length from the inner crossvein; last section of fifth vein distinctly longer than penultimate section; veins 3 and 4 slightly divergent at apices.

Reared by the writer at the Eastern Field Station of the Forest Insect Investigations, Bureau of Entomology, at Falls Church, Virginia.

Length, male, 4 mm.; female, 4.5 mm.

TYPE LOCALITY.—Falls Church, Va.

TYPE.—Female. Catalogue No. 21062, United States National Museum.

ALLOTYPE.—Male.

The male of this species has two distinctly abnormal bristles on the head, one in front of the postvertical pair and the other in the right fronto-orbital row.

LARVA

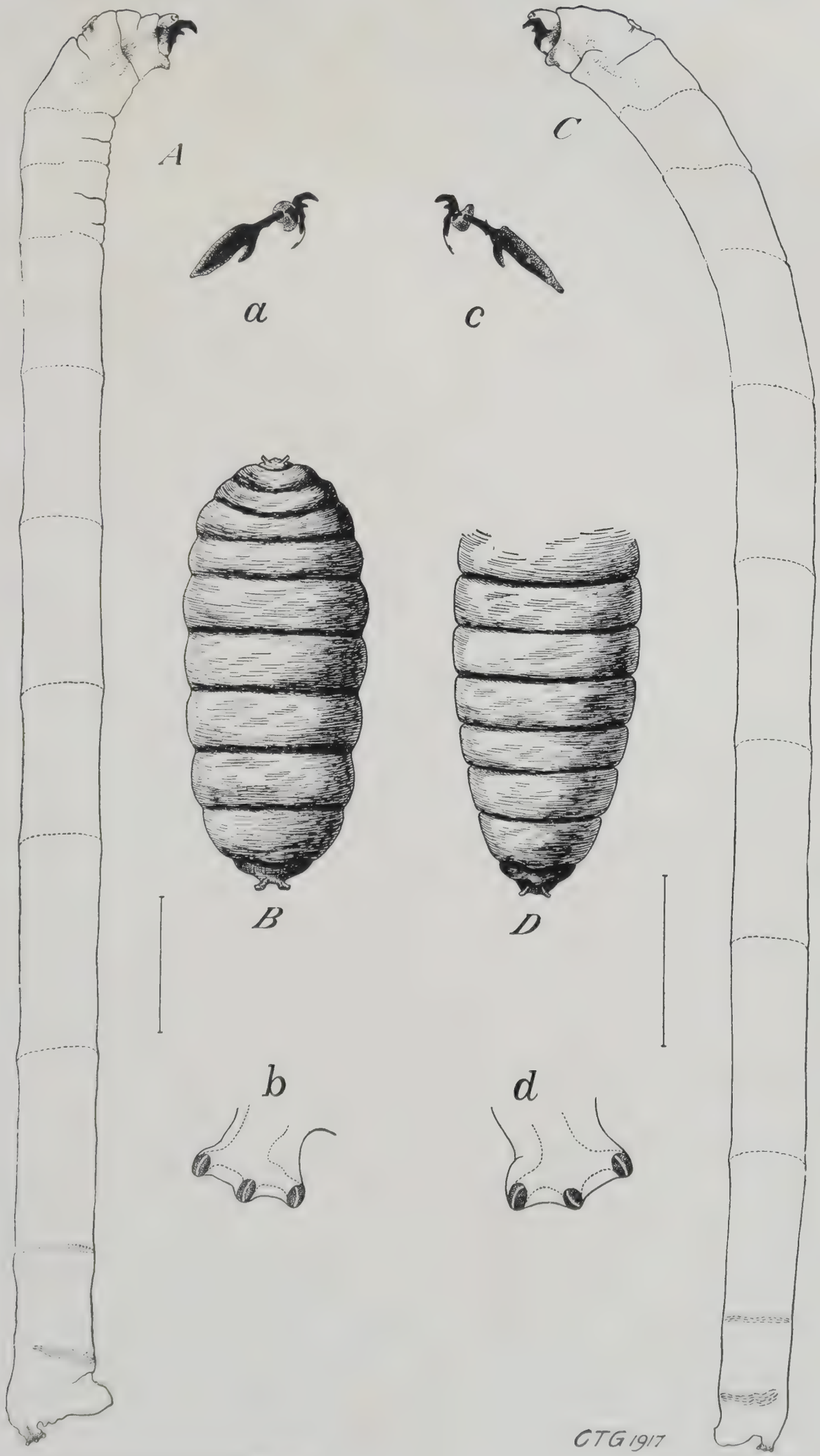
The larva (Pl. 48, *A*) is opaque white, cylindrical, and tapering very slightly at extreme anterior and posterior ends. Head segment small and not retractile. Above the hooklet and attached to it is a small, fleshy, conical portion. On each side of this conical portion, near the apex, is a small, black, chitinous, transverse plate with two small, black, cylindrical, chitinous pieces between and perpendicular to these two transverse plates. The hooklet complete (cephalopharyngeal skeleton) is shown in Plate 48, *A*, *a*. It is divided into two parts. The apical portion is black and highly chitinized and the greater part of it is exposed. The upper portion extends forward in the form of a large, robust, clawlike tooth; below this are two smaller teeth extending obliquely forward. The tooth on the right side of the larva is smaller than that on the left. The bottom terminates in a sharp toothlike point above which are attached two narrow, brownish, chitinous bands extending slightly below the bottom point. Just above the lower end of, and attached to the band, is a small, blacker chitinous piece. These bands appear to afford muscle attachment for operating the hooklet. The back terminates in a short, stout, oblique point where it articulates with the basal portion. On each side and in front of this rear point is attached a brownish black chitinous plate which is nearly quadrate and is attached along its anterior edge. This plate resembles an eye in the larva. The basal portion of the hooklet has a rather peculiar construction and is quite elongate and flattened. The

is not known. Mr. Brooks states that flies issued at French Creek from April 13 to 17, 1916, and that adults were collected from branches and buds at the same locality on April 18, 1916.

Nearly full-grown larvæ were collected at Smoky Mountain Crest, on the boundary line between Tennessee and North Carolina, on July 14, 1913, by Mr. T. E. Snyder.

PLATE 48

A.—*Agromyza aceris:* Larva. *a*, Cephalopharyngeal skeleton; *b*, posterior spiracle.
B.—*Agromyza aceris:* Pupa.
C.—*Agromyza amelanchieris:* Larva. *c*, Cephalopharyngeal skeleton; *d*, posterior spiracle.
D.—*Agromyza amelanchieris:* Pupa.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TOUGHNESS OF BITUMINOUS AGGREGATES

By CHARLES S. REEVE, *Chemist*, and RICHARD H. LEWIS, *Assistant Chemist, Office of Public Roads and Rural Engineering, United States Department of Agriculture*

INTRODUCTION

The following investigation was instituted as a result of certain observations on the part of one of the authors through an extended inspection of a large mileage of bituminous-concrete roads in New England. The mixes were largely of the one-size stone type, using crusher run of approximately the size that would pass a 1¼-inch screen and be retained on a ½-inch screen. The predominating rocks used were field stone of granitic or gneissoid character. The exceptions were a few sections constructed with quartzite or trap rock. Coal-tar binders were used almost exclusively in this work, and in most cases they were fluid products of about the consistency commonly required for hot-surface applications.

The careful inspection of a large mileage of roads constructed by the mixing method with the materials above noted showed conclusively a more pronounced and frequently quite rapid failure of sections in which trap rock or quartzite was used than in those sections constructed with native field stone. In fact, the difference in behavior was so marked that one engineer ventured the observation that trap rock was not adapted to bituminous construction. The excellent behavior of the tar trap-rock sections constructed by the same method and exposed to heavy traffic at Jamaica, N. Y.,[1] offered positive evidence to the contrary, although it is to be noted that a heavier grade of tar product was used than had been the case in the New England work. There appeared, however, to be no room for doubt that various rocks behaved differently in combination with the same bitumen, and it was in an endeavor to determine, if possible, what particular characteristic was responsible for the difference in behavior that the experimental work described in this paper was undertaken.

EXPERIMENTAL DATA

A number of large representative samples of various types of rock were selected, including those which had been under observation in the construction above referred to. The samples were passed through a small jaw crusher and reduced to particles ranging in size from ¼ inch

[1] PROGRESS REPORTS OF EXPERIMENTS IN DUST PREVENTION AND ROAD PRESERVATION, 1911. U. S. Dept. Agr. Off. Pub. Roads Circ. 98, 47 p. 1912.

in diameter to dust. The particles were separated into definite sizes by screening and were then recombined in fixed proportions with the object of producing an aggregate that, on a small scale, fairly well represented the one-size stone aggregate. The accurately proportioned aggregate was heated and mixed with a predetermined proportion of bituminous material. In order that the relative amount of bitumen to aggregate would be the same in all mixtures, the precentage was figured as a rational proportion, taking into account the specific gravity of both the rock and bitumen in accordance with the suggestion of Hubbard.[1] The aggregate and bitumen were heated separately to 150° C. and then thoroughly mixed together, after which the mix was allowed to cool to 105° and maintained at that temperature in a 105° oven until the test specimens were molded. The specimens were 25 by 25 mm. cylinders, compressed with a die and plunger under a pressure of 132 kgm. per square centimeter on the machine commonly used for preparing specimens in rock testing to show their cementing values.[2] At the end of 24 hours and of 7 days the cylinders were tested for toughness on the Page impact machine[2] with a 500-gm. hammer. The specimens were stored under cover in the laboratory until half an hour before testing, and during the 7-day period were immersed in water at 25° in order to bring them to a uniform temperature for testing. An average was taken of the results on three cylinders, and it may be stated that in all cases the three cylinders gave results in very close agreement.

Rocks of which the physical tests are given in Table I were used in the first series of experiments. After crushing, the particles were recombined in the following proportion:

Passing 8-mesh, retained on 10-mesh sieve..... 25 per cent.
Passing 10-mesh, retained on 20-mesh sieve..... 25 per cent.
Passing 20-mesh, retained on 50-mesh sieve..... 50 per cent.

TABLE I.—*Physical tests of rock used in preliminary toughness work*

No.	Rock.	Locality.	Specific gravity.	Weight per cubic foot.	Wear.	French coefficient.	Hardness.	Toughness.	Cementing value.	Absorption.
				Lbs.	*P.ct.*					
6112	Biotite gneiss	Fairfield, Conn	2.62	163	3.0	13.3	18.0	11	16	1.02
5589	Quartzite	Providence, R. I	2.61	162	4.4	9.0	19.3	16	5	.47
1817	Metamorphic sandstone	Newport, R. I	2.72	170	4.8	8.3	18.3	16	17	.59
7316	Diabase	Montgomery County, Md	2.92	182	1.9	20.6	19.2	28	102	.45
7682	Biotite gneiss	Delaware County, Pa	2.79	174	2.8	14.3	18.6	13	14	.20
7445	Sandstone	Picture Rocks, Pa	2.66	166	2.6	15.5	19.2	19	43	1.72
4813	Open-hearth slag	Cape Breton, Canada	3.29	205	3.1	12.9	.....	.....	500+	1.68
7332	Limestone	Jack County, Tex	2.66	166	3.8	10.6	14.1	6	118	1.27
6710	Blast-furnace slag	Canal Dover, Ohio	2.81	175	2.4	16.5	11.4	5	300	.....
4444	Basalt	Cowlitz County, Wash	2.75	171	2.5	16.1	18.5	14	7	1.77
1820	Chlorite gneiss	Providence, R. I	2.78	173	4.6	8.6	15.7	8	17	.46
871	.....do	Louisa County, Va	3.55	221	8.1	4.9	.....	3	.....	.16

[1] HUBBARD, PRÉVOST. THE BITUMEN CONTENT OF COARSE BITUMINOUS AGGREGATES. *In* Proc. Intern. Assoc. Testing Materials, v. 2, no. 11, art. 25, pt. 2, 7 p. 1912.

[2] JACKSON, F. H., Jr. METHODS FOR THE DETERMINATION OF THE PHYSICAL PROPERTIES OF ROAD-BUILDING ROCK. U. S. Dept. Agr. Bul. 347, 27 p., 12 fig. 1916.

Two grades of refined water-gas tar, X and Y, were used. The latter was of the consistency used frequently in bituminous-concrete construction, and that there might be no question about the similar character of the two tars, X was prepared by adding a proper amount of heavy water-gas-tar distillate to Y, producing a tar of the consistency used commonly in hot surface treatment, and also in bituminous concrete in some New England localities, as noted above. In addition to these two tars, a residual petroleum, No. 6408, an oil asphalt, No. 6409, and a fluxed native asphalt, No. 5767, were used. The characteristics of all the bituminous materials are given in Tables II and III.

TABLE II.—*Analyses of water-gas tar*

Sample No.	X	Y	X′	Y′
Specific gravity (25°/25° C.)	1. 168	1. 184	1. 162	1. 184
Float test (32° C.)	1′ 48″	.....	1′ 44″	.....
Float test (50° C.)	49″	2′ 21″	.....	2′ 50″
Bitumen soluble in carbon bisulphid, per cent.	99. 23	99. 25	99. 23	99. 23
Organic matter insoluble (free carbon), per cent.	0. 72	0. 70	0. 75	0. 72
Inorganic matter insoluble.....per cent.	0. 05	0. 05	0. 02	0. 05
Distillate (270°–315° C.) by weight, per cent.	.....	.....	13. 4	2. 48
Pitch (over 315° C.) by weight...per cent.	.....	.....	86. 6	97. 43

TABLE III.—*Analyses of petroleum and asphalt products*

Sample No.	6408 A	6409 B	5767 C	8950 D	8949 E	8948 F	8748 G
Material	Residual petroleum.	Oil asphalt.	Fluxed native asphalt.	Oil asphalt.	Oil asphalt.	Oil asphalt.	Fluxed native asphalt.
Specific gravity (25°/25° C.)	0. 988	1. 010	1. 044	1. 036	1. 046	1. 048	1. 050
Specific viscosity (Engler 100° C.)	47	.....	.....	.....	.....	.....	.....
Float test (32° C.)	7′ 20″	.....	.....	.....	.....	.....	.....
Float test (50° C.)	1′ 45″	.....	.....	.....	.....	.....	.....
Melting point (° C.)	.....	54	52. 5	45. 7	51. 8	62. 4	44
Penetration (100 gm., 5 sec., 25° C.)	.....	111	122	145	91	50	118
Loss (163° C., 5 hours)	1. 17	0. 62	3. 08	0. 46	0. 16	0. 09	1. 16
Float test of residue (50° C.)	2′ 38″	.....	.....	.....	.....	.....	.....
Penetration of residue (25° C.)	.....	78	65	87	55	37	65
Bitumen soluble in carbon bisulphid.....per cent.	99. 96	99. 96	95. 54	99. 95	99. 92	99. 84	95. 69
Organic matter insoluble, per cent.	0. 04	0. 04	1. 84	0. 05	0. 06	0. 10	1. 12
Inorganic matter insoluble, per cent.	0	0	1. 62	0	0. 02	0. 06	3. 19
Total bitumen insoluble in 86° B. naphtha..per cent.	21. 35	28. 14	22. 29	25. 65	29. 47	29. 76	24. 32
Fixed carbon.....per cent.	11. 08	13. 65	10. 62	15. 26	17. 60	18. 05	12. 52

A rational volume proportion of 88 per cent of aggregate to 12 per cent of bitumen was adopted, and the weight proportions for each combination of materials was figured on the basis of this volume ratio.

All the cylinders in the first series of tests were broken at the end of 24 hours, and the results are given in Table IV. Where zero toughness is indicated, the cylinder was deformed by the mere weight of the plunger's resting upon it. The results in Table IV are tabulated in the order of the increasing strength of the cylinders containing the lightest water-gas tar, and, for convenience, the physical tests of the rocks in Table I are given in the same order. The difference in the relative binding value of the different mixtures is clearly apparent, and it also is definitely shown that certain rocks yield a relatively tough mixture in combination with what generally would be considered a rather fluid tar for bituminous construction. However, it will be noted that there is no single physical property which appears to be responsible for this difference in behavior when the rocks are combined with a bituminous material.

TABLE IV.—*Toughness tests on bituminous-aggregate cylinders*

No.	Rock.	Toughness.				
		Refined water-gas tar.	Refined water-gas tar.	Residual petroleum.	Oil asphalt.	Fluxed native asphalt
		X	Y	A	B	C
6112	Biotite gneiss	0	7	1	4	10
5589	Quartzite	0	10	2	5	12
1817	Metamorphic sandstone	0	13	3	6	12
7316	Diabase	0	14	2	5	13
7682	Biotite gneiss	3	9	2	5	9
7445	Sandstone	4	12	4	5	13
4813	Open-hearth slag	6	14	0	5	10
7332	Limestone	6	17	8	8	14
6710	Blast-furnace slag	7	11	3	4	10
4444	Basalt	7	12	5	6	11
1820	Chlorite gneiss	8	15	6	9	14
871	.....do	10	17	4	8	15

Upon the disclosure of these interesting differences, for which no explanation was apparent, a second series of tests was decided upon in which several possible sources of error could be avoided. The crushed material, for instance, was obtained directly from the block out of which had been cut the sections for specific gravity and absorption and the core pieces for hardness and toughness, whereas in the first series the crushed rock was taken from that remaining in a sack after the regular laboratory tests had been made. This change in method tied up the physical tests directly with the material used in preparing the bituminous aggregates. In order to reduce to some extent the possibility of errors due to varia-

tions in the relative proportions of different size particles in one of the fractions of crushed aggregate used, a 30-mesh screen was introduced in separating the aggregate. The mineral aggregate for the second series of cylinders was therefore proportioned as follows:

Passing 8-mesh, retained on 10-mesh screen..... 25 per cent.
Passing 10-mesh, retained on 20-mesh screen..... 25 per cent.
Passing 30-mesh, retained on 50-mesh screen..... 50 per cent.

It is likely that this elimination of an intermediate size of particle is partly responsible for the uniformly lower results obtained throughout the second series. The physical tests on the rocks used are given in Table V. The bituminous materials consisted of refined water-gas tars practically identical with those used in the first series, three oil asphalts of 145, 91, and 50 penetration, respectively, and a fluxed native asphalt. The data regarding these materials will be found in Tables II and III.

TABLE V.—*Physical tests of rocks used in second series of toughness tests*

Lab. No.	Rock.	Locality.	Specific gravity.	Weight per cubic foot.	Wear.	French coefficient.	Hardness.	Toughness.	Cementing value.	Absorption.
				Lbs.	*P. ct.*					
10101	Diabase	Montgomery County, Md.	3.05	190	1.4	28.6	18.5	21	.....	0.35
9093	Biotite schist	Cumberland, Me.	2.75	171	6.1	6.6	18.0	8	35	.41
10108	Quartzite	Minnehaha, S. Dak.	2.67	167	2.8	14.3	19.3	17	5	.68
9445	Biotite granite	Knox County, Me.	2.64	165	3.1	12.9	19.7	17	12	.40
9095	Biotite gneiss	Cumberland County, Me.	2.74	171	4.8	8.3	18.8	8	30	.26
9094	Altered diabase porphyry.	Cumberland, Me.	2.94	184	2.3	17.4	18.3	18	44	.27
8136	Feldspathic sandstone	Montgomery County, Md.	2.46	153	4.8	8.3	15.5	5	111	3.15
8992	Open-hearth slag	Mahoning County, Ohio.	3.60	228	4.7	8.5	.....	....	84	.12
9321	Feldspathic quartzite	Fulton County, Ga.	2.63	163	5.1	7.8	18.5	20	8	.33
8993	Blast-furnace slag	Mahoning County, Ohio.	2.89	180	7.7	5.2	18.0	14	96	1.18
8989	Chlorite gneiss	Jamestown, R. I.	2.70	168	6.2	6.5	18.0	14	20	.21
9281	Limestone	Seneca County, Ohio.	2.66	166	4.3	9.3	13.5	7	20	2.16

Before deciding upon the proportions of bitumen to be used in this series of tests, a number of cylinders were made up with concrete sand which had been screened and reproportioned in the same manner as adopted for the rock-test pieces. The oil asphalt 8950 was used, and the results in three cylinders for each proportion are given in Table VI. Since the proportion of 88 aggregate to 12 bitumen, which was used in the first series of tests, gave within one point of the highest toughness obtained, it was decided to continue its use through the second series. This series of results with the sand and bitumen mixtures shows very clearly within what narrow limits the percentage of bitumen should be controlled in order to obtain its maximum efficiency as a binder. By taking the highest toughness obtained, which is 11, it will be seen that this was produced within a range of bitumen content of 0.43 per cent by weight and that well-defined decreases continue from this maximum by either reducing or increasing the bitumen content.

TABLE VI.—*Effect on toughness of variation of rational proportion of bitumen and sand*

Test No.	Rational proportion.		Percentage of bitumen by weight.	Toughness.
	Rock.	Bitumen.		
1	93	7	2.86	3–3–3
2	92	8	3.29	4–4–4
3	91	9	3.72	6–6–6
4	90	10	4.15	7–7–7
5	89	11	4.58	8–8–8
6	88	12	5.01	10–10–10
7	87	13	5.44	11–11–11
8	86	14	5.87	11–10–11
9	85	15	6.30	10–10–10
10	84	16	6.73	9–9–9
11	83	17	7.16	8–8–8
12	82	18	7.59	6–6–6
13	81	19	8.02	5–5–5

For the more complete information of the reader Table VII gives the percentage by weight of each bituminous material used with each rock. In this and all other tables the rocks are arranged in the order of increasing toughness with the light refined water-gas tar at the end of 24 hours. The results obtained in this series are given in Table VIII. While, as above noted, they are uniformly lower than those obtained in the first series, it will be seen that the various rocks bear the same general relation to each other, as shown in Table IV, for the first series of tests. With the light water-gas tar X′, for instance, the diabase and quartzite continue to exhibit no strength whatever, while the chlorite gneiss shows up well from a strength standpoint. This bears out fully the observations made in the actual construction work which led to this investigation, where the bulk of the work referred to was constructed with these three types of rock, and the chlorite gneiss was the only one which showed any pronounced success in combination with the relatively fluid tar binders. It also may be noted with interest that the feldspathic sandstone 8136 shows a marked weakness in combination with all the binders, which is clearly shown in the right-hand column of averages of all results obtained on each type of rock. This accords with some results obtained recently in actual practice on experimental sections constructed by this office. The same rock from which a sample was taken for these tests was used in a one-size stone bituminous concrete with both oil asphalt and fluxed native asphalt of 102 and 117 penetration, respectively. The section began to check and crack almost immediately, and in a few months began to fail so generally that a surface treatment was necessary in order to save it.

TABLE VII.—*Percentages of weight of bitumens used in mixtures on basis of rational proportion of 88 parts of mineral aggregate to 12 parts of bitumen*

Sample No.	Name of rock.	Specific gravity of rock.	Percentage by weight.					
			Refined water-gas tar.		Oil asphalt.	Oil asphalt.	Oil asphalt.	Fluxed native asphalt.
			X′	Y′	8950	8949	8948	8748
	Sand	2.65	5.65	5.75	5.06	5.10	5.12	5.13
10101	Diabase	3.05	4.93	5.03	4.42	4.46	4.47	4.48
9093	Biotite schist	2.78	5.39	5.49	4.83	4.90	4.91	4.92
10108	Quartzite	2.67	5.60	5.70	5.05	5.06	5.08	5.09
9445	Biotite granite	2.65	5.65	5.75	5.06	5.10	5.12	5.13
9095	Biotite gneiss	2.73	5.48	5.58	4.92	4.96	4.98	4.99
9094	Altered diabase porphyry	2.94	5.11	5.20	4.58	4.62	4.63	4.64
8136	Sandstone	2.54	5.87	5.97	5.27	5.31	5.32	5.34
8992	Open-hearth slag	3.55	4.27	4.36	3.82	3.86	3.88	3.89
9321	Feldspathic quartzite	2.67	5.60	5.70	5.05	5.06	5.08	5.09
8993	Blast-furnace slag	2.93	5.13	5.22	4.60	4.64	4.66	4.67
8989	Chlorite gneiss	2.75	5.45	5.55	4.88	4.93	4.94	4.95
9281	Limestone	2.72	5.50	5.60	4.94	4.98	5.00	5.02

TABLE VIII.—*Toughness tests on bituminous aggregate cylinders (second series)*

No.	Rock.	Toughness.												Average.
		24 hours.						7 days.						
		Refined water-gas tar.		Oil asphalt.			Fluxed native asphalt.	Refined water-gas tar.		Oil asphalt.			Fluxed native asphalt.	
		X′	Y′	D	E	F	G	X′	Y′	D	E	F	G	
	Sand	0	7	10	8	7	12	0	6	9	7	7	10	6.92
10101	Diabase	0	8	9	7	7	10	0	9	9	9	9	10	7.25
9093	Biotite schist	0	10	9	7	7	10	0	11	8	9	8	11	7.50
10108	Quartzite	0	10	9	9	8	8	0	11	12	11	8	10	8.00
9445	Biotite granite	0	11	10	8	8	11	0	11	9	7	8	11	7.83
9095	Biotite gneiss	0	6	9	10	8	11	1	9	9	8	9	12	7.67
9094	Altered diabase porphyry	0	11	9	9	9	11	5	12	10	10	7	12	8.75
8136	Feldspathic sandstone	1	7	8	5	5	6	4	6	6	5	5	7	5.42
8992	Open-hearth slag	2	11	8	9	7	10	2	12	11	11	8	10	8.42
9321	Feldspathic quartzite	2	13	10	9	10	12	3	15	9	9	9	12	9.42
8993	Blast-furnace slag	2	9	8	8	7	8	4	10	8	8	7	12	7.58
8989	Chlorite gneiss	3	11	7	9	8	10	4	11	8	8	7	11	8.08
9281	Limestone	6	11	10	8	7	10	9	14	10	8	8	13	9.50
	Average	1.23	9.62	8.92	8.15	7.54	9.92	2.46	10.54	9.08	8.46	7.70	10.85	....

In direct reference to these service results a review of some of the data developed in the two series of tests discloses some important relations. It will be noted, for instance, that the limestone, blast-furnace slag, and two chlorite gneisses show the lowest toughness of any of the rocks used in the first series. In combination with certain bituminous binders,

however, they yield toughness results which exceed, in some cases, those obtained with the solid rock itself. The limestone, with a toughness of 6, in only one case shows as low a toughness as this with a binder, and in combination with the refined water-gas tar Y develops a toughness of 17. The chlorite gneiss (871), which has a toughness of 3, in no case has as low a toughness as this when combined with any of the bituminous binders which were used; and in combination with the refined water-gas tar Y and the fluxed native asphalt, it yields toughness results as high as 17 and 15, respectively. A reference to Tables V and VIII shows the same behavior with most of the binders for the biotite schist, biotite gneiss, and, more noticeably, for the limestone. In comparing these tables it will be noted that all the binders fail to produce a relatively high toughness with the feldspathic sandstone, whose service results were referred to above. From these results it would appear that some modification of the toughness limits for bituminous macadam suggested by Hubbard and Jackson [1] could well be made to admit rocks of lower toughness than they would otherwise admit, provided such rocks can be made to develop a mixture of sufficient toughness through the introduction of a bituminous binder. In addition to cases heretofore cited where this has been done successfully the utilization of the coralline rocks or soft limestone of Florida offers an excellent example of the possibilities of such a practice. The majority of these rocks are so soft that a toughness cylinder can not be cut from them, but they have been used in bituminous macadam to form a tough and durable wearing surface when combined with a properly selected bituminous binder.

As a matter of interest the results obtained with each bituminous material have also been averaged in Table VIII, showing that the fluxed native asphalt gives the highest average result, with the heavy refined tar, Y′, a close second. A reference to these averages also shows that for the proportion of bitumen used in these tests the strength of the oil-asphalt specimens decreases with increase in hardness of the binder. It will be noted, however, that, as in the first series of tests, there is no apparent direct relation between any one physical characteristic of the rock and its behavior with a bituminous binder.

With the object of learning whether any single component of the rocks was responsible for this difference or behavior, the mineral composition of each was tabulated in the same order used in the other tables. The analyses, made in accordance with the method used in the laboratory of the Office of Public Roads and Rural Engineering,[2] are given in Table IX. From these results there does not appear to be any definite relation between the mineral composition and the toughness.

[1] HUBBARD, PRÉVOST, and JACKSON, F. H., jr. THE RESULTS OF PHYSICAL TESTS OF ROAD-BUILDING ROCK. U. S. Dept. Agr. Bul. 370, p. 11. 1916.

[2] LORD, E. C. E. RELATION OF MINERAL COMPOSITION AND ROCK STRUCTURE TO THE PHYSICAL PROPERTIES OF ROAD MATERIALS. U. S. Dept. Agr. Bul. 348, 26 p., 3 fig., 8 pl. 1916.

TABLE IX.—*Petrographic analyses of crystalline rocks used in toughness cylinders (second series)*

Rock.	Diabase (10101).	Biotite schist (9093).	Quartzite (10108).	Biotite granite (9445).	Biotite gneiss (9095).	Altered diabase porphyry (9094).	Feldspathic sandstone (8136).	Open-hearth slag (8992).	Feldspathic quartzite (9321).	Blast-furnace slag (8993).[a]	Chlorite gneiss (8989).
Augite	43.8	.....	.....	.....	.....	52,2	.....	.....	.....	.....	.....
Plagioclase	43.2	16.2	.....	16.4	.....	36.3	4.7	.....	.....	.....	.....
Orthoclase	.....	27.2	.....	38.8	26.6	.....	49.3	.....	63.8	.....	.....
Quartz	.....	31.4	94.2	32.1	54.0	.....	26.1	.....	28.8	.....	38.4
Biotite	.6	18.6	.....	6.4	16.8	.....	.....	.....	2.4	.....	2.8
Muscovite	.....	1.0	.....	.....	2.6	.....	1.0	.....	3.0	.....	.....
Limonite	.....	.....	.....	.....	.....	.....	18.7	.....	.....	.....	.....
Chlorite	5.6	.....	.....	.....	.....	.....	.2	.....	.....	.....	48.2
Epidote	.....	.....	.....	.....	.....	.....	.....	.....	.8	.....	3.9
Kaolin	3.4	3.6	2.6	5.8	.....	.....	.....	.....	.....	.....	.....
Hematite	.....	.....	3.2	.....	.....	.....	.....	.....	.....	.....	.....
Magnetite	3.4	1.0	.....	.5	.....	5.9	.....	.....	.....	.....	2.6
Garnet	.....	.....	.....	.....	.....	.....	.....	.....	1.0	.....	4.1
Apatite	.....	.4	.....	.....	.....	.....	.....	.....	.....	.....	.....
Titanite	.....	.6	.....	.....	.....	.....	.....	.....	.....	.....	.....
Pyrite	.....	.....	.....	.....	.....	.....	.....	.....	1.2	.....	.....
Calcite	.....	.....	.....	.....	.....	.2	.....	.....	.....	.....	.....
Serpentine	.....	.....	.....	.....	.....	5.4	.....	.....	.....	.....	.....
Belite	.....	.....	.....	.....	.....	.....	.....	49.8	.....	.....	.....
Iron ferrite	.....	.....	.....	.....	.....	.....	.....	47.2	.....	.....	.....
Iron	.....	.....	.....	.....	.....	.....	.....	3.0	.....	.....	.....

[a] Not analyzed.

On realizing that changes in the size of particles in the aggregate might have resulted from the effects of compressing the cylinders, the bitumen was extracted from the aggregates after the tests had been made, and the rock particles were graded again by sieve analysis. The results so obtained are given in Table X. Interesting changes were noted in the proportioning of the aggregate and, whereas none of the cylinders originally contained any particles passing a 50-mesh screen, one of them, No. 8989, now contained 37.65 per cent passing this screen. The relative proportion of all the sizes of particles have been changed materially, but a careful study of the results fails to reveal any explanation of the problem under discussion.

TABLE X.—*Grading of aggregate from cylinders after compression with percentage of voids in compressed cylinders*

No.	Sieve analysis.				Unfilled voids in cylinders.
	Retained on—			Passing 50-mesh.	
	10-mesh.	20-mesh.	50-mesh.		
Sand	20.65	24.90	41.80	12.65	23.9
10101	19.65	32.30	35.75	12.30	26.8
9093	13.90	28.75	36.50	20.85	26.1
10108	17.00	28.60	33.90	20.30	25.4
9445	14.00	30.55	35.95	19.50	23.2
9095	13.90	28.40	35.90	21.80	26.2
9094	14.25	30.65	40.73	14.35	25.8
8136	15.10	26.50	28.90	29.50	26.4
8992	16.05	27.75	37.70	18.50	25.5
9321	14.80	30.75	33.25	21.20	24.2
8993	15.40	28.65	41.05	14.90	27.7
8989	11.10	25.05	26.20	37.65	24.2
9281	17.00	26.50	31.75	24.75	21.0

The last column of Table X gives the calculated unfilled voids in each type of test piece. They represent the percentage difference between the actual specific gravity of the test pieces found by dividing their weight by their volume, and their ideal specific gravity calculated from the specific gravities and the percentage by weight of their constituents.

When it was found that no physical tests could be correlated directly with the behavior of the rocks in mixtures, it was suggested that the surface character and cleavage of the particles might be responsible for the differences. An examination with a hand glass seemed to show some interesting differences in surface character, and in order to permit a more careful investigation enlarged photographs of a few 10-mesh particles of each rock were made. Reproductions are shown in the accompanying plates. Plate 49 shows the first six rocks in Table VIII. These are of low average toughness and all fail to show any toughness with the light tar, except the biotite gneiss (9095) which gives a toughness of 1 at seven days. These rocks are large grained and made up of individual glassy particles, and therefore may be characterized as possessing smooth surfaces. This is most evident in the case of the sand, which had the lowest average toughness of any of the materials shown in Plate 49. In Plate 50 are shown fragments of the rocks which gave the relatively higher toughness values, except the sandstone (8136). It will be noted that the surface condition of these particles is quite different from those in Plate 49 on account of the fine-grained, relatively rough surface. The photograph of the feldspathic quartzite (9321) fails to show this character as clearly as desirable, but it can be stated that the fragments have a decidedly dull or frosted appearance, probably due to the feldspar content, as compared with the glassy quartzite (10108) in Plate 49. A comparison of the photographs with the toughness results would therefore seem to offer one explanation for the difference in the behavior of the various rocks, and these differences appear, to some extent at least, to be due to the fact that polished, glassy faces of the rocks in Plate 49 fail to hold the bitumen as well as the rougher surfaces of the rocks shown in Plate 50. An exception is noted in the case of the sandstone (8136) shown in Plate 50. The particles of this rock present a decidedly rough, dull surface, but the rock in combination with all bituminous materials showed the lowest average toughness of any tested, owing to the fact that the individual particles of the specimen were bound together loosely. In fact, the rock could be crumbled in the hand without very great difficulty. As noted above, a bituminous concrete section in which this rock was used failed rapidly and this was evidently due to the failure of the individual rock fragments rather than to the failure of the adhesion of the bitumen.

CONCLUSIONS

From the foregoing investigation and data the following conclusions may be drawn:

(1) The toughness of bituminous aggregates in which a given bituminous material is used will not be the same for every type of rock.

(2) Tests of laboratory specimens can be directly correlated with results in service.

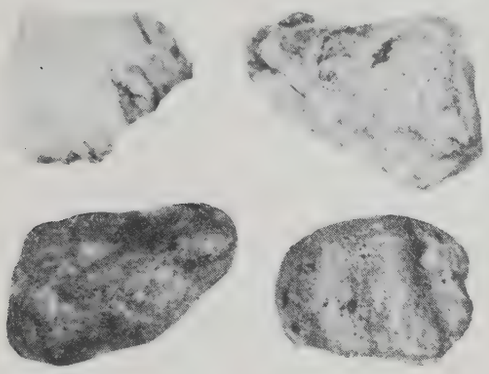
(3) The difference in behavior of the various rock types can not be directly attributed to any of the routine physical test values of the rock, but appears to be due largely to differences in the surface character of the rock particles.

(4) While relatively soft or fluid bitumens may yield satisfactory results in bituminous concrete with some types of rock, their use with other types will lead to failure of the road surface.

(5) The impact or toughness test of bituminous aggregates offers possibilities as a means of determining in advance the relative behavior in service of bituminous concretes. While the authors at this time have no definite recommendations to offer with regard to their last conclusion, it may be stated that further experiments will be made with that end in view.

PLATE 49

A.—Sand.
B.—Diabase (10101).
C.—Biotite schist (9093).
D.—Quartzote (10108).
E.—Biotite granite (9445).
F.—Biotite gneiss (9095).



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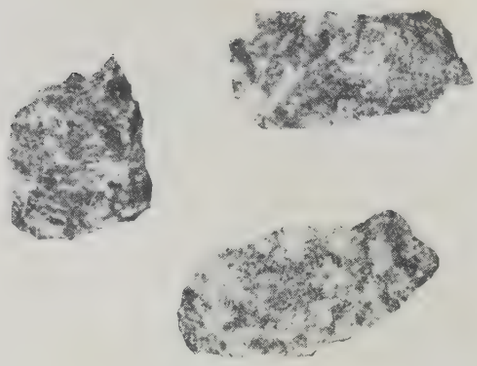

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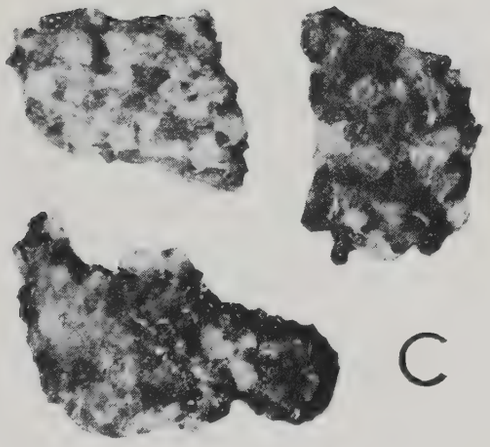

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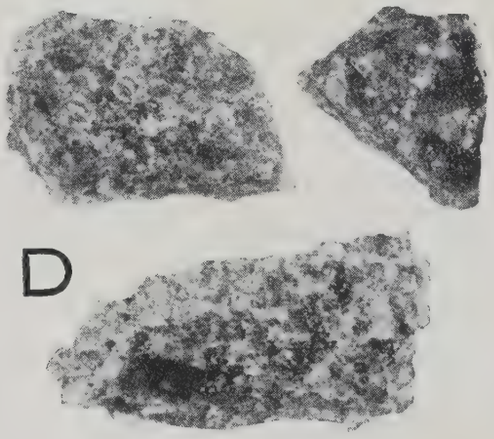

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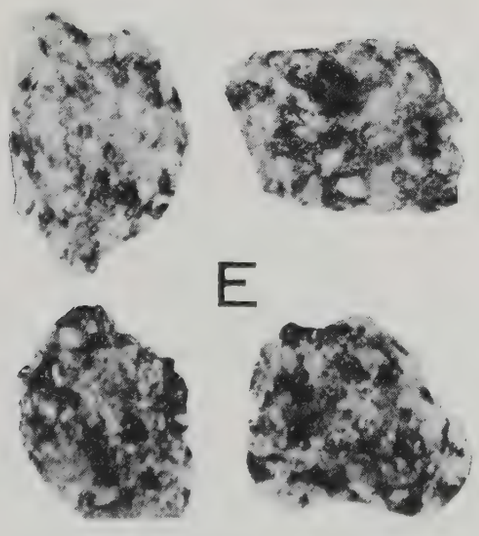

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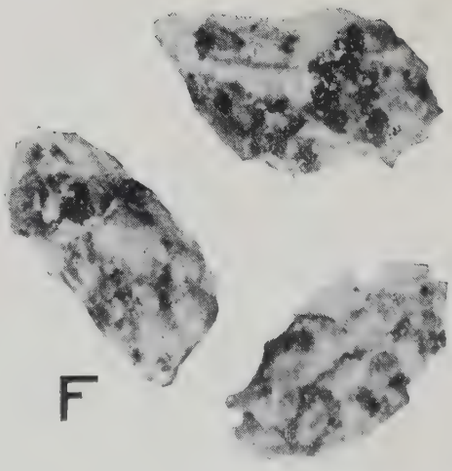

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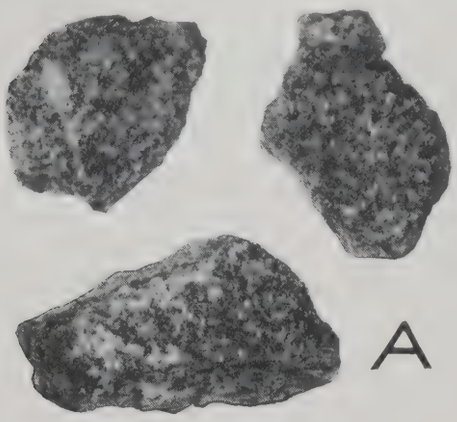
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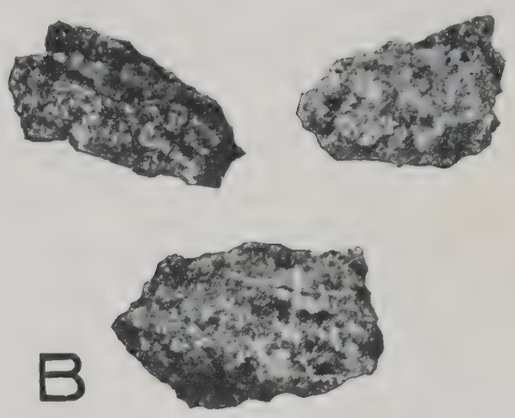
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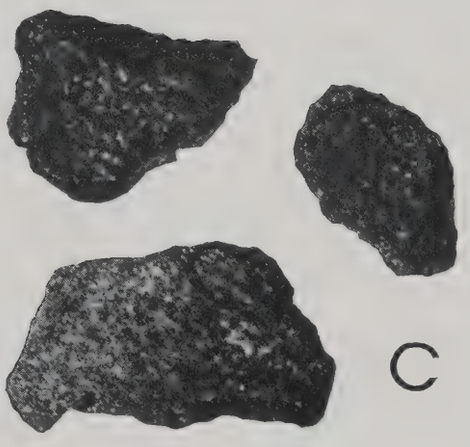
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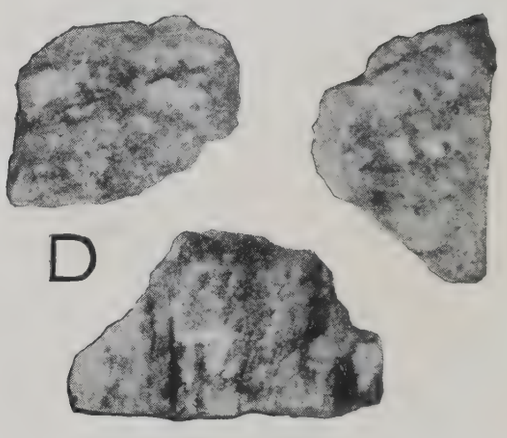
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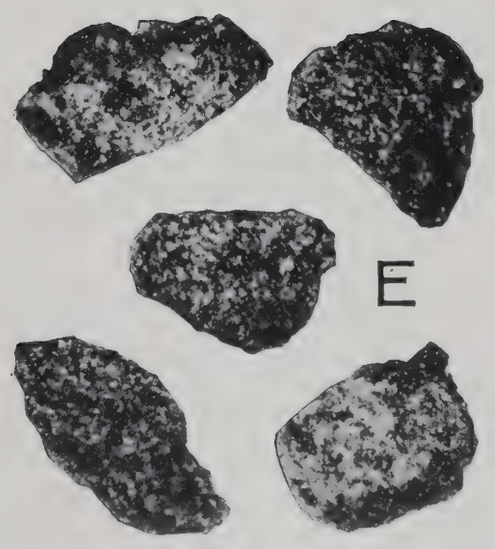
E

F

PLATE 50

A.—Altered diabase porphyry (9094).
B.—Feldspathic sandstone (8136).
C.—Open-hearth slag (8992).
D.—Feldspathic quartzite (9321).
E.—Chlorite schist (8989).
F.—Limestone (9281).

ORIGIN OF ALKALI

By ROBERT STEWART,[1] *Formerly Chemist*, and WILLIAM PETERSON, *Geologist, Utah Agricultural Experiment Station*

INTRODUCTION

The term "alkali" was probably first applied to the white incrustation on the dry arid plains by the hunters and trappers of the Far West long before the attention of the scientific man was directed to it. The term undoubtedly originated with them, because the wind carried fine white powder and deposited it in the dry parched mouth and nose of the traveler and seemed to increase the great distances between the watering places by this burning thirst and apparent caustic effect of the dry dust. The parched throat of the weary thirsty traveler felt as if it had been subjected to some caustic soda. Hence, the term "alkali" was applied to this white deposit. In addition, the early travelers and settlers of the Far West, being separated from the markets for caustic alkali, were forced to secure the alkali carbonates for soap making from the burning of the native bushes and trees such as greasewood, cedars, and pines. The analogy between the white deposits in the soil and the white caustic obtained from the ashes of vegetation was also possibly sufficient to the lay mind to cause the same term to be applied to both. Whatever the origin of the term, it has an unimportant chemical, but a very important agricultural, significance.

HISTORICAL REVIEW

The first record we have of its scientific investigation is in 1870. The Chemist to the Commissioner of Agriculture in his report (1, p. 96) [2] says:

> Dr. Edward Palmer brought to the laboratory from Western Kansas prairies a sample of what is called "alkali" of the western plains. It was in the form of a dry, milk-white powder, mixed with bleached leaves and coarse grass. It did not effervesce with acids, nor did it exhibit an acid reaction to test-paper. It contained:
>
> | | |
> |---|---|
> | Water | 3.6 |
> | Insoluble clay | 1.5 |
> | Chloride of sodium | traces. |
> | Sulphate of soda | 94.6 |
> | | 99.7 |
>
> It is consequently a native sulphate of soda. There is no evidence to show that it is a product of volcanic action. It may owe its origin to the decomposition of sulphate

[1] Now Associate Professor of Soil Fertility, University of Illinois.

[2] Reference is made by number to "Literature cited," p. 353.

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of lime, which is largely present in the soils at the foot of the Rocky Mountains and Sierra Nevada series, by means of carbonate of soda occurring as efflorescences on soil. The usual origin of sulphate of soda is either directly from volcanic sources, or by the delivery of springs containing salt derived from preexisting sedimentary beds. In a few cases it is derived from the oxidation of sulphur in bituminous strata, or in pyritiferous beds which, reacting on common salt, produce thenardite or other forms of sodic sulphate.

In 1876 the East India Government on petition appointed a committee to investigate and report on the increasing encroachments of "reh," a saline efflorescence on soil irrigated by canals. One member of this committee, Mr. Medlicott, Superintendent of the Geological Survey of India, says (6), regarding the origin of "reh":

> Every one seems content to accept the reh as an ultimate fact—that there it is—as much an original ingredient of the ground as the clay and sand. Now, I consider it demonstrated that this view is false, and that an origin is assignable for reh which introduces the gravest apprehensions as to the possible results of canal irrigation, The present chief store of reh is in the saline subsoil-water—the upper water-bed found more or less all over Upper India. Beneath this, at depths of from sixty to one hundred feet, sweet water is found, containing no more salt than the canal water, which is very pure. Now, I consider it certain that these upper deposits were originally as free from those salts as is now the alluvium of the delta; and that the present state has been brought about in the course of generations, slowly but with increasing rapidity, owing to the total subversion of the natural climatal conditions, chiefly by the total destruction of forest vegetation. The explanation is simple: every soil contains some reh, and all percolation water from soils is also contaminated by those salts, which are the refuse products (the parts unassimilated by vegetation) in the very slow process of formation and consumption of soil. Unless removed it must accumulate; and the natural process of purification is a certain necessary amount of percolation and ground drainage, the pure rain-water passing through the soil carrying off any injurious excess of these rejected salts. If the washing process is sufficiently free to insure a certain discharge of this percolation water by natural subsoil drainage, there will be a constant dilution and removal of the subsoil-water; but if the percolation through the soil is no more than to restore what has been dissipated by capillary action and evaporation during the dry season, the reh will go on accumulating in the upper water-table; and such has been the condition of Upper India for many a day.

Hilgard, soon after the beginning of his association with the University of California in 1874, began his classical work upon the various phases of the alkali problem. In his report to the president of the university in 1877, he says (5, p. 43), in a discussion of the origin of alkali:

> The immediate source of the alkali is usually to be found in the soil water, which, rising from below and evaporating at the surface, deposits there whatever of dissolved matters it may contain.

And the manner in which it gets its way into the soil water is fully discussed in the numerous subsequent publications on the subject by him and possibly is fully represented by the following direct quotation (6, p. 9):

> The same alkali salts are formed everywhere in the world; but in countries having abundant rainfall they are currently washed, as formed, into the country drainage, while in regions where rainfall is deficient, the scanty moisture only carries them a

little way down into the subsoil, from which they rise to the surface by the evaporation of the water, and are thus accumulated at, and close to, the very top of the soil, often in the form of crusts or crystals. It is right there that nearly all the damage is done; the water in the depths of the soil is very rarely strong enough to hurt the roots of plants, directly.

These direct quotations probably will represent the teachings of Hilgard regarding the origin of the alkali of arid soils.

Hilgard also emphasized the necessity of care in the use of saline irrigation waters (6, p. 41), which may intensify the alkali condition of the soil.

Many of the Experiment Stations of the West have published bulletins and reports dealing with the alkali question, but they have simply adopted Hilgard's conception of the origin of alkali and present no new views on the question.

A notable exception is found in the work of Buffum, who suggests a different origin (2, p. 219). He says:

In the Wheatland district, although the rainfall is too small to produce crops, and all farms are irrigated, no injurious alkali has appeared upon any of the uplands under cultivation. *The soil of the uplands here is colluvial and derived from earlier geological formations which do not supply the alkali salts.*

This view was further advocated by Slosson (8, p. 40):

The principal source of the alkali is not, however, the water used in irrigation, but the beds of soluble salts that are deep in the soil. As soon as water is put on the land these salts are drawn to the surface by evaporation.

Soon after the organization of the Bureau of Soils of the United States Department of Agriculture its attention was directed to the alkali problems of the West. Regarding the origin of alkali in certain soils at Billings, Mont., Whitney and Means (11, p. 35) say:

The results of these investigations show that the ultimate source of the alkali is in the sandstone, and particularly in the shale or slate rocks from which the soils have been derived.

It is, however, not clear as to the condition in which they occur or the manner of the transfer to the soils. Fortunately in a later publication (4, p. 10) of the Bureau additional information is furnished upon this point.

In a few cases the genesis of alkali can be clearly traced. For instance, in the Billings area, Montana, * * * it seems obvious that the source of the material is found in the sulphides of iron prevalent in the Fort Benton shales, which on exposure to the air oxidize to the sulphates and then on contact with water hydrolyze, forming sulphuric acid and ultimately the sulphates of the alkalies and alkaline earths.

Various other theories are also discussed regarding the origin of alkali, such as deposition from wind-blown spray and Cameron's (4, p. 11) conception of the derivation of alkalies by means of hydrochloric and sulphuric acid resulting from the weathering of the original rock, which, as Clarke shows (3, p. 17), contains an average of 0.07 per cent of chlorin

and 0.108 per cent of sulphuric acid. Regarding the conception of the derivation from preexisting geological deposits, Dorsey (4, p. 10) says:

> In some cases it may be regarded as fairly evident that the salts do come from more or less deep-seated deposits resulting from the desiccation at more or less remote periods of time of bodies of sea water. In many cases, however, there is a total lack of confirmatory geologic evidence, and this explanation must be regarded as very unsatisfactory.

It may thus be seen that there are a number of theories proposed regarding the origin of "alkali" of the arid regions. The following are some of the most important: (1) Derivation from gypsum by action of sodium carbonate, as proposed by Antisell; (2) accumulation of the unused portion of the soil or refuse, as proposed by Medlicott; (3) Hilgard's conception of the formation of soluble salts in the soil by ordinary process of weathering and their concentration in the lower depths by the action of the limited rainfall; (4) Whitney and Means's conception of their formation by oxidation of the sulphids of the shales; (5) Buffum's view of the presence of isolated deposits or lakes of the alkali salts in the country rock; (6) Cameron's theory regarding the formation of hydrochloric and sulphuric acid from the chlorin and sulphur content of the country rock and the subsequent leaching action of these acids on the insoluble silicates of the soil or rock; and (7) the deposition by wind spray from sea water.

THE PROBLEM

Our attention was directed forcibly toward the alkali problem in connection with our investigation regarding the origin of the "niter spots," a special phase of the more general alkali problem.

The results of these investigations, which have been presented elsewhere (9), led us to a very definite conception regarding the origin of alkali in at least a large portion of Utah, Colorado, Wyoming, Montana, Alberta, Canada, and undoubtedly in many other areas of the arid region. The preponderance of evidence submitted by us clearly demonstrates that the "niter spots" are the direct result of the leaching action of water upon the nitrates preexisting in the country rock and their concentration at the points of greatest evaporation. The nitrate accumulations are always accompanied by the other water-soluble so-called alkali salts. The facts led us to formulate a definite hypothesis regarding the origin not only of the nitrates themselves but also of the other salts as well.

The hypothesis upon which the following work was based is: The "alkali" is derived from the soluble salts preexisting in the country rock of the observed area. This country rock rich in alkali not only contributes to the soil formation but is adjacent to and underneath the agricultural soils of the affected areas. The original soil may not have sufficient salts present to prevent crop production, but upon the application of the irrigation water the alkali salts existing in the country

rock are leached out and concentrated in the surface soil. Leaky irrigation canals and the rise of the ground-water table give greatest and quickest concentrations.

GEOLOGIC FORMATIONS

Field studies were made of the area during the years 1913 and 1914, when some 400 representative samples of sandstone, shale, alkali, clay, and ash[1] were collected and later submitted to complete "alkali" analysis. The data of the nitric and potassium content have been presented and discussed elsewhere (9, 10).

The geological evidence shows that during the Cretaceous and the Tertiary periods shallow seas covered the eastern part of Utah, western Colorado, western Wyoming, eastern Idaho, and extended north through Montana into Canada (9, map). This is not the whole area covered, but the part given special study in this paper. The Lower Cretaceous is wanting, and the Upper Cretaceous lies unconformable on the Jurassic deposit. The climate during the Jurassic was arid, as is evidenced by the great areas of red sandstone containing rock salt and great quantities of gypsum. During the Lower Cretaceous the area was land and suffered erosion. The divisions of the periods in general are as follows:

Arrangement of geologic formations

Tertiary	Eocene	Green River formation, Wasatch, Fort Union.	Light-colored sandstone, limestone, and shale with beds of rhyolitic ash and lenses of salt and gypsum. Coal beds and layer of dark-colored shale. Forms floor of Uintah Basin.	
Upper Cretaceous	Montana	Mesaverde	Alternating layers of buff sandstone and shale with beds of workable coal near base.	2,000–4,000 feet in thickness.
	Colorado	Mancos	Black and blue-gray shale with light-colored sandstone near top.	1,000–3,000 feet in thickness.
		Dakota	Buff sandstones, highly colored shale with carbonaceous shale and some coal at the base.	300–2,500 feet in thickness.
Unconformity.				
Jurassic			Brown-, yellow-, and red-colored sandstone with lenses of limestone and gypsum.	500–2,000 feet in thickness.

When the sea again covered the land at the end of Lower Cretaceous times, conglomerates, sandstone, and shale were deposited; and during the Upper Cretaceous the sea continued to deepen during the period of deposition. But at times the sea was shallow, forming layers or salty marshes in which gypsum and salt were deposited. The shales of the Mancos, which are more than 2,000 feet thick in places, contain beds which are heavily impregnated with gypsum, sodium sulphate, and some sodium chlorid. The deposit is not uniform, but appears in certain beds irregularly distributed through the deposit.

[1] A term which was chosen to apply to a mixture of dry dust with crystals of alkali found just under the clay crust on the most affected parts.

The Mesaverde contained much colored sandstone and the coal deposit of the period. The sandstone shows much cross-bedding, marks, etc., indicating shallow water deposits.

The sea partially disappeared at the end of the Mesaverde, so the Tertiary strata lies unconformably on it over large areas. The climate of the Tertiary was similar to the Upper Cretaceous, and much of the material deposited in the Tertiary seas was derived from the weathered Cretaceous. The salts in the shallow seas seem to have their origin in the concentrating of sea waters encroaching on the land.

It is out of this material, heavily impregnated with the alkali salts, that many of the soils of the arid West are formed. The climate continued to be arid, and the salts deposited with the shale and sandstone in a widely disseminated form have been protected from leaching not only by the limited rainfall of the area but also by the impervious covering of plastic clay resulting from the weathering of the shale.

METHOD OF ANALYSIS

The ground-up rock or soil was extracted with pure distilled water in the ratio of 1 part of fine-ground rock to 20 parts of water. Usuallly whenever the quantity of rock would permit, 100 gm. of the rock material was treated with 2,000 c. c. of water for eight hours in a shaking machine. The extract was then filtered through a Chamberland-Pasteur filter by means of compressed air.

The soil extract was analyzed for total salts, calcium, magnesium, carbonic acid, sulphuric acid, chlorin, potassium, and nitric nitrogen. The methods of analysis, except for nitric nitrogen, were essentially those of the Association of Official Agricultural Chemists[1] for alkali waters. Owing to the high content of chlorin, the aluminium reduction method as proposed by Moore (7) was used for the determination of nitrates as follows: 200 c. c. of the soil extract were boiled down to small volume to expel all free ammonia. The solution was then transferred to 125 c. c. test tubes, and 2 c. c. of strong sodium hydroxid and about 1 gm. of aluminium foil added. The tube was then fitted with one-hole rubber stopper containing a tube drawn out to a capillary. The reduction was allowed to go on at about 21° to 22° C. for about 12 hours. The solution was then transferred to a 500-c. c. Kjeldahl flask, 150 c. c. of ammonia-free water added, the ammonia distilled into standard sulphuric acid (*N*/30), and the excess titrated against standard alkali (*N*/30), using lacmoid as an indicator.

SOLUBLE SALTS IN CRETACEOUS SANDSTONE

Twelve samples of Cretaceous sandstone were collected and analyzed for water-soluble salts; the results are recorded in Table I as pounds per 2,000,000 of sandstone. The results are arranged in the table in the order of the highest nitric-nitrogen content.

[1] WILEY, H. W., ed. EXTRACTS FROM THE PROCEEDINGS OF THE ASSOCIATION OF OFFICIAL AGRICULTURAL CHEMISTS, 1909. U. S. Dept. Agr. Bur. Chem. Circ. 52, 32 p. 1910.

TABLE I.—*Soluble salts in Cretaceous sandstone*

[Results expressed as pounds per 2,000,000 of material]

Field No.	Location of sample.	Calcium (Ca).	Magnesium (Mg).	Carbonic acid (CO_3).	Sulphuric acid (SO_3).	Chlorin (Cl).
260A	Thompson, Utah	1,042	280	1,040	461	Trace.
73	Grand Junction, Colo.	48,120	38,880	880	106,744	2,552
80	do	3,074	2,257	333	31,710	1,300
292	Vernal, Utah	160	768	480	1,216	Trace.
81	Grand Junction, Colo.	802	1,384	383	5,980	2,127
279	Vernal, Utah	1,202	769	600	1,514	Trace.
88	Green River, Utah	1,470	276	350	4,829	Do.
290	Vernal, Utah	1,042	629	640	2,503	Do.
242	Superior, Wyo	802	943	640	1,136	Do.
244	do	1,058	1,835	1,480	19,360	1,701
245	do	1,604	1,694	1,200	1,218	567
241	do	802	2,237	720	494	567
Average	Cretaceous	5,098	4,329	729	14,764	170

All the samples of Cretaceous sandstone contain appreciable quantities of soluble salts and are especially rich in sulphates with appreciable quantities of carbonic acid and chlorin, and, as already reported, they all contain nitric nitrogen. From the analytical data reported above, the probable chemical combination may be calculated in any manner desired. Some such calculations have been made in the manner suggested by the Association of Official Agricultural Chemists.

On this basis of calculation, with the average results reported above, all the carbonates, sulphates, chlorids, and nitrates present in the Cretaceous sandstone consist of calcium and magnesium compounds. There remains also a slight excess of magnesium after these acid ions are satisfied, which undoubtedly represents that united with the phosphoric and silicic acids. These soluble salts undoubtedly exist in the rock in the crystalline form with water of crystallization; but the amount of this water of crystallization was not determined, the results being simply calculated to the anhydrous basis. There is present in these sandstones, therefore, 983 pounds of calcium bicarbonate [$Ca(HCO_3)$], 16,469 pounds of calcium sulphate, 3,922 pounds of magnesium sulphate, 985 pounds of magnesium chlorid, and 1,961 pounds of magnesium nitrate—that is, over 1.21 per cent of the sandstone consist of these soluble salts. The leaching of such rock by the irrigation and ground water must result in a concentration of these salts where the seepage or ground water approaches the surface. The concentration of such soluble salts of calcium and magnesium will bring about double decomposition with the formation of soluble salts of sodium, such as the chlorid and sulphate. However, it must be remembered that the sandstone and shale may and do become mixed in the soil formation in some areas. The soil derived entirely from the sandstone, however, should not contain such an excess of soluble salts of a harmful nature as to be destructive to crop growth. There may be and undoubtedly are other reasons why the alkali problem is not

so vital in the sandy soils of the area, but the fact that the salts in the sandstone are largely the salts of calcium and magnesium is one important reason.

SOLUBLE SALTS IN CRETACEOUS SHALE

Fifty-seven samples of Cretaceous shale were collected and analyzed for soluble salts. The results are recorded in Table II as pounds per 2,000,000 of shale.

As an average, the Cretaceous shale is much richer in sulphates and chlorids than is the sandstone. Again, the sulphates are the predominating salts. There is little less calcium in the shale than in the sandstone, while the latter contains over twice as much magnesium as the former. The increase in sulphates and chlorids is due to the presence of the salts of sodium.

As an average, there are present in this shale 993 pounds of calcium bicarbonate, 15,738 pounds of gypsum, or calcium sulphate, 10,780 pounds of magnesium sulphate, 13,036 pounds of sodium sulphate, 1,148 pounds of sodium chlorid, and 2,079 pounds of sodium nitrate—that is, at least 2.19 per cent of this shale material consist of water-soluble salts. Some samples are markedly rich in the soluble salts, while others are not so rich. But all the samples contain some soluble salts, and, unlike the sandstone, the shale contains large quantities of the more harmful sulphate and chlorid of sodium.

There is, of course, a marked variation in the composition of the soluble salts. In some samples there is no soluble calcium, while in others there is no soluble magnesium. In one sample there are no soluble carbonates, but the solution is really acid. Many samples contain no chlorin, or at least only traces of this acid ion.

There is no definite ratio between the various acidic or basic elements in the several samples. The sample which is richest in chlorids, No. 84 from Green River, contains only moderate amounts of sulphates. It is much richer in calcium than the average, but is not the richest in calcium. It contains less than the average amount of magnesium and nearly the average amount of carbonic acid. It contains nearly the maximum amount of nitric nitrogen, yet there are other samples of shale which are richer in nitric nitrogen but which contain only traces of chlorin. The sample which is richest in sulphate, No. 8126 from Emery, Utah, contains only traces of chlorin, no carbonic acid, moderate amounts of calcium and magnesium. The 12 per cent of soluble sulphates consist largely of the compounds of magnesium and sodium. This sample is a coal-bearing shale, the definite strata of coal being seen with the naked eye. It was obtained just below an economic supply of undeveloped coal near Emery, Utah. Its aqueous solution was highly colored a dark brown. This lack of any definite ratio is exactly what one would expect. The salts were deposited from the saline water of the old inland seas, and isolated playas would undoubtedly become more concentrated in some salts than others

TABLE II.—*Soluble salts in Cretaceous shale*

[Results expressed as pounds per 2,000,000 of material]

Field No.	Location of sample.	Calcium (Ca).	Magnesium (Mg).	Carbonic acid (CO_3).	Sulphuric acid (SO_3).	Chlorin (Cl).
68	Grand Junction, Colo.	7,699	3,154	480	46,408	567
294	Vernal, Utah	481	978	240	1,342	302
274	Thompson, Utah	1,042	961	1,280	6,321	2,556
264	do	13,152	6,220	800	101,400	Trace.
79	Grand Junction, Colo.	5,948	4,135	300	42,800	Do.
261	Thompson, Utah	1,388	1,083	680	44,904	425
69	Grand Junction, Colo.	1,609	13,276	320	25,016	213
84	Green River, Utah	9,960	699	666	44,110	7,562
86	do	802	219	667	7,530	2,009
123	Emery, Utah	722	Trace.	1,440	20,080	709
89	Green River, Utah	3,743	335	383	28,580	235
65	Grand Junction, Colo.	3,369	358	240	15,669	None.
98	Price, Utah	2,004	205	533	11,180	236
75	Grand Junction, Colo.	5,133	8,247	640	42,800	None.
262	Thompson, Utah	4,331	4,736	760	44,216	284
78	Grand Junction, Colo.	21,488	3,215	560	74,536	Trace.
66	do	1,122	716	1,000	22,154	284
281	Vernal, Utah	1,090	419	1,560	2,304	284
289	do	1,765	524	960	571	Trace.
102	Price, Utah	2,606	Trace.	533	12,840	Do.
130	Emery, Utah	11,398	1,049	760	63,967	284
95	Price, Utah	2,810	873	466	17,120	118
100	do	1,470	Trace.	700	1,936	Trace.
67	Grand Junction, Colo.	11,660	1,464	300	26,504	567
144	Emery, Utah	320	752	1,280	6,748	284
85	Green River, Utah	8,754	495	367	31,650	Trace.
83	Grand Junction, Colo.	10,893	7,241	200	61,960	Do.
90	Price, Utah	None.	516	433	9,742	Do.
97	do	1,938	Trace.	500	12,896	Do.
286	Vernal, Utah	1,764	978	720	103,360	Do.
76	Grand Junction, Colo.	6,738	2,796	780	37,600	Do.
110	Orangeville, Utah	2,967	1,552	560	11,728	284
99	Price, Utah	2,049	Trace.	200	16,874	Trace.
108	Castledale, Utah	5,453	Do.	600	27,032	213
287	Vernal, Utah	1,684	786	600	39,768	Trace.
105	Castledale, Utah	1,524	Trace.	760	2,370	284
63	Grand Junction, Colo.	8,260	716	260	21,428	284
64	do	10,988	349	300	26,992	284
116	Emery, Utah	10,824	1,136	280	21,104	Trace.
119	do	3,047	718	540	8,876	Do.
91	Price, Utah	301	437	566	3,512	1,359
291	Vernal, Utah	962	961	360	2,338	Trace.
268	Uintah, Utah	1,042	974	1,080	1,876	Do.
113	Orangeville, Utah	8,100	2,788	1,080	33,912	425
269	Uintah, Utah	1,604	1,031	1,594	2,864	Trace.
S126	Emery, Utah	4,009	29,188	None.	256,400	Do.
271	Uintah, Utah	1,203	1,066	1,080	1,251	None.
120	Emery, Utah	10,986	585	560	47,472	425
122	do	2,726	Trace.	640	22,976	567
117	do	642	Do.	2,120	28,440	142
107	Castledale, Utah	15,756	Do.	1,600	184,720	16,872
71	Grand Junction, Colo.	1,042	11,184	440	12,472	Trace.
270	Thompson, Utah	1,123	908	840	790	None.
280	Vernal, Utah	386	577	2,040	1,284	Do.
278	do	882	629	1,920	2,238	426
128	Emery, Utah	802	1,695	840	30,320	Trace.
Average	Cretaceous	4,898	2,156	728	28,159	675

This shale, so highly impregnated with the sulphates, chlorids, and nitrates of calcium, magnesium, sodium, and potassium, is the sole material out of which many of the soils of the area are made. In certain small areas the sandstone, also rich in soluble salts, contributes to the soil formation, while in still other small areas the river wash from other geological horizons contribute to the soil formation. But the major portion of the land of the area investigated is derived from the Mancos shale of Cretaceous origin. The irrigating canals of the region, run by gravity, are diverted from the rivers high up on the stream and, as a result, cut through the shale strata in many places. The shale, broadly speaking, is nearly horizontal, and the strata lie like the leaves of a book. The irrigation canal cuts this strata in the higher-lying ground, and, as a result, the seepage water from the canal follows the folds of the shale to the point of outcrop where the soluble salts, concentrated from the entire shale area covered, are deposited on evaporation of the water. The result is a good crop of alkali or an alkali bog. In certain isolated basins the problem is intensified by the rise of the ground water, with its solvent action upon the undecomposed shale. This is the sole origin of the alkali of the observed area.

SOLUBLE SALTS IN THE CRETACEOUS ASH

As already reported, there appears on the surface of the slight decomposed shale a mealy mass of white-gray material which has a burnt-ash-like appearance. The material is crystalline when examined with a hand lens. On placing under the microscope for examination, it largely dissolves on the addition of water. Eight representative samples of this were collected and analyzed. The results are recorded in Table III.

TABLE III.—*Soluble salts in Cretaceous ash*

[Results expressed as pounds per 2,000,000 of material]

Field No.	Location of sample.	Calcium (Ca).	Magnesium (Mg).	Carbonic acid (CO_3).	Sulphuric acid (SO_3).	Chlorin (Cl).
133	Emery, Utah	11,308	3,552	5,200	129,680	5,389
77	Grand Junction, Colo.	12,192	10,206	240	255,200	1,418
124	Emery, Utah	722	Trace.	1,040	44,568	900
260	Thompson, Utah	19,808	978	840	114,600	852
276	Vernal, Utah	7,377	3,600	640	127,960	709
134	Emery, Utah	Trace.	559	9,600	14,416	Trace.
145	do	6,576	4,662	880	102,800	1,276
122a	do	1,764	Trace.	1,240	71,408	709
Average	Cretaceous	7,468	2,807	795	93,193	1,400

This ash material found on the surface of the shale represents the accumulation of salts due to the solvent leaching and evaporation of rain or ground water.

The soluble carbonate in the ash is nearly the same as in the shale, while the magnesium has slightly increased. The calcium has nearly doubled, while the chlorin has more than doubled. The sulphates have increased by over three times. There are 1,073 pounds of calcium bicarbonate present, 21,743 pounds of calcium sulphate, 14,035 pounds of magnesium sulphate, 99,910 pounds of sodium sulphate, 2,380 pounds sodium chlorid, and 3,623 pounds of sodium nitrate—that is, in this ashlike material the concentration of salts has become such that 7.13 per cent of the total material consist of the sulphates, chlorid, nitrates, and carbonates of calcium, magnesium, sodium, and potassium. This accumulation has been brought about in the virgin native condition by the concentrating action of the limited rainfall. It is strongly indicative of the more intensive action which may be brought under the irrigated conditions due to the leaky irrigation ditch and the rise of the ground water.

SOLUBLE SALTS IN THE UNCULTIVATED SOIL AND CLAY

Twelve samples of the clay or soil resulting from the weathering of the shale in place were collected and submitted to analysis. This clay or soil has never been cultivated and does not even support a virgin crop of grass or weeds. These samples are fairly representative of the kind of soil formed in place from the shale. The results are recorded in Table IV.

TABLE IV.—*Soluble salts in uncultivated soils and clay*

[Results expressed as pounds per 2,000,000 of material]

Field No.	Location of sample.	Calcium (Ca).	Magnesium (Mg).	Carbonic acid (CO_3).	Sulphuric acid (SO_3).	Chlorin (Cl).
277	Vernal, Utah	51,328	1,887	1,120	58,040	2,410
263	Thompson, Utah	4,973	2,132	760	36,376	Trace.
87	Green River, Utah	4,812	233	383	15,968	599
131	Emery, Utah	8,829	839	800	43,744	425
96	Price, Utah	7,953	1,019	400	28,090	Trace.
85	Green River, Utah	8,754	495	367	36,184	Do.
146	Emery, Utah	5,694	7,656	920	112,880	4,253
121	do	8,260	525	620	34,704	284
125	do	1,363	Trace.	920	36,672	Trace.
143	do	160	769	1,200	9,480	3,800
Average	Cretaceous	5,593	1,556	749	41,213	1,176

The amount of calcium in the clay is slightly higher than in the shale, while the magnesium is slightly less. The carbonic acid is practically constant in the shale and clay. The sulphuric acid has materially increased, as has also the chlorin.

As an average, there are 1,021 pounds of calcium bicarbonate in the clay, 18,091 pounds of calcium sulphate, 7,780 pounds of magnesium sulphate, 9,411 pounds of sodium sulphate, 1,999 pounds of sodium

chlorid, and 775 pounds of sodium nitrate. Again, the predominating acid ion is the sulphate, followed closely by chlorin—that is, this uncultivated clay contains 1.75 per cent of water-soluble salts and over one-half of the salts consists of sodium and magnesium sulphates. Is it any wonder that these clay hills do not support any native vegetation? Such a soil when underlain by the characteristic ash reported above is certainly too concentrated for the most resistant crops.

"ALKALI" OF CRETACEOUS ORIGIN

As already reported, characteristic alkali spots occur in the native condition in the uncultivated clay hills wherever moisture conditions are such as to bring about a concentration of the water-soluble salts of the shales or sandstones. These alkali spots may be found near springs or bogs in these hills. Twenty-three samples of such alkali were collected and analyzed for soluble salts. This alkali has no connection with irrigation canals. The results, which show enormous accumulations of soluble salts in these native alkali spots, are recorded in Table V.

TABLE V.—*Soluble salts in the "alkali" of Cretaceous origin*

[Results expressed as pounds per 2,000,000 of material]

Field No.	Location of sample.	Calcium (Ca).	Magnesium (Mg).	Carbonic acid (CO_3).	Sulphuric acid (SO_3).	Chlorin (Cl).
132	Emery, Utah	13,712	11,016	None.	371,920	16,304
77	Grand Junction, Colo.	12,192	None.	240	255,200	1,418
275	Thompson, Utah	19,408	597	1,360	76,080	567
94	Price, Utah	10,960	29,840	1,632	182,280	2,670
72A	Grand Junction, Colo.	9,945	111,840	4,720	103,500	3,686
127	Emery, Utah	8,018	58,016	920	58,144	11,416
114	Castledale, Utah	7,779	86,480	2,640	5,517	50,192
101	Price, Utah	10,426	21,888	1,500	207,040	6,145
295	Vernal, Utah	8,100	2,045	600	226,800	Trace.
82	Grand Junction, Colo.	5,948	5,126	517	44,048	None.
137	Emery, Utah	22,456	2,255	240	44,780	5,246
129	do	4,571	8,760	4,440	61,160	2,694
112	Orangeville, Utah	12,188	35,652	2,240	467,360	33,320
282	Vernal, Utah	2,807	1,136	29,160	189,440	11,485
70	Grand Junction, Colo.	15,078	88,200	20,800	903,360	12,336
109	Castledale, Utah	17,963	Trace.	3,040	310,720	31,760
103	Price, Utah	14,840	29,810	1,300	275,500	3,345
136	Emery, Utah	23,420	612	800	56,848	587
72	Grand Junction, Colo.	4,892	8,424	480	65,776	284
126	Emery, Utah	802	Trace.	920	1,448	None.
118	Rochester, Utah	7,777	4,710	2,520	197,440	32,328
111	Orangeville, Utah	15,960	52,136	1,200	352,800	2,269
115	Castledale, Utah	12,429	26,652	1,720	263,360	12,052
Average	Cretaceous	11,376	25,447	2,533	245,805	10,391

These virgin alkali spots are especially rich in sulphates of magnesium and sodium. Calculations as before show that there are 3,419 pounds of calcium bicarbonate, 35,666 pounds of calcium sulphate, 127,235 pounds of magnesium sulphate, 152,682 pounds of sodium sulphate, 17,665

pounds of sodium chlorid, and 5,492 pounds of sodium nitrate per 2,000,000 pounds as an average of 23 determinations of alkali from widely separated portions of the Cretaceous area—that is, in this crude alkali material collected in the uncultivated soil there is 17.10 per cent soluble in water.

In our previous publications (9, 10) attention was called to the fact that the niter spots were not characteristic of cultivated irrigated soil, but were found in the virgin condition wherever the moisture condition was suitable for a concentration of the salts. Special attention was directed to one such spot, as represented by samples 130, 131, 132, and 133, representative of the shale, soil, alkali, and ash, respectively. Now that the complete data are available, it is interesting and instructive to study these samples again. The complete data are given in Table VI.

TABLE VI.—*Soluble salts in material from a native niter spot*

[Results expressed as pounds per 2,000,000 of material]

Field No.	Sample.	Calcium bicarbonate.	Calcium sulphate.	Magnesium sulphate.	Sodium sulphate.	Sodium chlorid.	Sodium nitrate.
130	Shale	1,026	37,508	5,240	49,962	483	899
131	Clay or soil	1,080	29,066	4,195	29,807	723	768
132	Alkali	None.	46,620	55,080	442,407	297,168	67,080
133	Ash	7,020	32,259	12,760	130,051	8,161	65,380

In this characteristic niter spot occurring in the virgin soil we find that the accumulations of nitrates are accompanied by accumulations of other soluble salts such as the chlorids and sulphates of calcium, magnesium, and sodium. The parent shale contains 4.75 per cent of soluble salts, over one-half, or 52.4 per cent, of which is sodium sulphate; 10 per cent of calcium bicarbonate; 0.51 per cent of sodium chlorid; 0.94 per cent of sodium nitrate. In the soil derived from this shale there are 3.23 per cent of soluble salts in which the sulphates of sodium and calcium are about equal—that is, 45.4 per cent is sodium sulphate, 44.2 per cent is calcium sulphate, 8 per cent magnesium sulphate, 1.65 per cent calcium bicarbonate, 1.10 per cent sodium chlorid, 1.17 per cent sodium nitrate. In the alkali there are 45.5 per cent of total soluble salts with a marked increase in the chlorid, sulphur, and nitrate of sodium. Of the total soluble material 48.6 per cent is the sulphate of sodium, 32.1 per cent is the chlorid of sodium, 7.4 per cent is the nitrate of sodium, 6.05 per cent is the sulphate of magnesium, 5.13 per cent is the sulphate of calcium, while the bicarbonate of calcium is entirely missing. In fact, the aqueous extract of the alkali is acid to methyl orange. The ash contains 12.78 per cent of soluble salts, of which 50.9 per cent is the sulphate of sodium, 12.6 per cent is the sulphate of calcium, 5 per cent is the sulphate of magnesium, 25.5 per cent is the nitrate of

sodium, 2.8 per cent is the bicarbonate of calcium, 3.2 per cent is the chlorid of sodium. For convenience these results are brought together in Table VII.

TABLE VII.—*Percentage composition of alkali obtained from shale, soil, and ash*

Field No.	Sample.	Calcium bicarbonate.	Calcium sulphate.	Magnesium sulphate.	Sodium sulphate.	Sodium chlorid.	Sodium nitrate.
130.....	Shale.....	1.0	39.4	5.5	52.4	0.5	0.9
131.....	Soil.....	1.7	44.2	8.0	45.4	1.1	1.2
132.....	Alkali.....	.....	5.1	6.1	48.6	32.1	7.4
133.....	Ash.....	2.8	12.6	5.0	50.9	3.2	25.5

This characteristic niter spot is abundantly supplied with the sulphates of calcium, magnesium, and sodium. The proportion of the bicarbonate and magnesium sulphate varies but little. The chlorid and nitrate increase from a small proportion in the shale to relatively large amounts in the ash and alkali. The origin of the nitrate, as well as the other salts in the clay, ash, and alkali, is definitely traceable to the alkali-salt content preexisting in the shale itself. The color of the brown alkali is due to the old organic matter of the shale, which in this case lies immediately beneath economic coal deposits occurring in the shale.

SOLUBLE SALTS IN TERTIARY SANDSTONE

The samples of Tertiary sandstone collected represent widely separated portions of the Tertiary deposits. Owing to the lack of material, not all the samples reported in Utah Bulletin 134 (9) have been analyzed. The Tertiary sandstone is not so rich in alkali salts as is the Cretaceous sandstone. The results for the four representative samples is recorded in Table VIII as pounds per 2,000,000 of sandstone. There is less of all material in this sandstone except chlorin.

TABLE VIII.—*Soluble salts in the Tertiary sandstone*

[Results expressed as pounds per 2,000,000 of material]

Field No.	Location of sample.	Calcium (Ca).	Magnesium (Mg).	Sulphuric acid (SO_3).	Carbonic acid (CO_3).	Chlorin (Cl).
273.....	Uinta Basin, Utah...	2,085	1,223	4,543	760	851
283.....	Lyman, Wyo.....	1,042	2,830	4,806	840	3,403
312.....	Utahn, Utah.....	410	760	395	800	Trace.
203.....	Millburn, Wyo.....	1,532	786	1,415	3,240	Do.
Average...	Tertiary.....	1,265	1,400	2,790	1,410	1,064

There is only 0.5 per cent of soluble salts present in the sandstone, which is about equally divided between the various salts of calcium and

magnesium. As in the Cretaceous sandstones, the sodium salts are entirely absent. There are 1,904 pounds of calcium bicarbonate present in 2,000,000 of sandstone, 2,621 pounds of calcium sulphate, 1,175 pounds of magnesium sulphate, 1,426 pounds of magnesium chlorid, and 2,530 pounds of magnesium nitrate. Again, there is a slight excess of magnesium which, no doubt, is united with phosphoric and silicic acids. The soluble salts in the sandstone amount to 0.45 per cent. The results of the analysis of the Tertiary shales are recorded in Table IX.

TABLE IX.—*Soluble salts in Tertiary shales*

[Results expressed as pounds per 2,000,000 of material]

Field No.	Location of sample.	Calcium (Ca).	Magnesium (Mg).	Carbonic acid (CO_3).	Sulphuric acid (SO_4).	Chlorin (Cl).
30	Richfield, Utah	54,920	5,680	1,200	13,252	12,052
310	Utahn, Utah	722	1,267	1,080	5,235	8,706
236	Lyman, Wyo	722	262	1,200	1,580	8,224
31	Sigurd, Utah	25,904	3,503	480	60,800	35,876
308	Utahn, Utah	722	1,468	1,480	1,646	2,797
300	Myton, Utah	6,576	646	480	923	20,704
232	Lyman, Wyo	561	873	2,840	9,944	7,656
299	Myton, Utah	160	960	2,000	1,811	2,326
223	Lyman, Wyo	1,600	489	1,600	7,572	711
307	Myton, Utah	241	1,136	3,120	1,877	284
304	do	321	314	1,640	5,531	681
233	Lyman, Wyo	4,813	786	920	4,974	2,269
36	Sigurd, Utah	5,936	2,009	320	1,409	2,474
305	Myton, Utah	160	262	600	1,908	1,702
215	Millburn, Wyo	240	411	2,480	3,720	284
222	Lyman, Utah	5,133	856	640	37,828	709
229	do	481	507	1,720	1,086	1,418
208	Millburn, Wyo	1,764	1,223	800	6,058	850
272	Vernal, Utah	882	873	3,000	4,280	Trace.
205	Millburn, Wyo	3,849	1,800	6,400	16,296	567
210	do	21,412	3,512	760	67,984	567
33	Sigurd, Wyo	1,042	None.	800	2,204	Trace.
211	Millburn, Wyo	321	...do...	880	None.	Do.
212	do	401	...do...	2,080	Trace.	142
213	do	321	...do...	2,720	None.	Trace.
306	Myton, Utah	2,406	1,380	800	71,800	Do.
32	Sigurd, Utah	642	363	320	3,391	Do.
39	Richfield, Utah	962	114	580	699	213
214	Lyman, Wyo	560	None.	720	None.	Trace.
Average...	Tertiary	7,316	1,058	1,307	18,341	4,603

A comparison of these shales with the Cretaceous shales brings out a number of interesting points. Less magnesium and more chlorin is found in the shales of Tertiary origin, and there is more calcium and carbonic acid and less sulphuric acid. A marked difference occurs in the amount of chlorin present, there being over seven times as much chlorin, on an average, in the Tertiary shales as in the Cretaceous. This is the most conspicuous difference.

As an average, there occur to the acre 1,764 pounds of calcium bicarbonate, 23,320 pounds of calcium sulphate, 2,350 pounds of magnesium chlorid, 4,826 pounds of sodium chlorid, and 3,362 pounds of nitrate—that is, an average of 1.90 per cent of these shales is soluble in water and over 50 per cent of the salts consist of calcium sulphate or gypsum. The concentration of this material by underground-water movement, together with double decomposition, must result in enormous concentration of water-soluble salts.

The results of the analysis of the soluble-salt content of the ash is recorded in Table X. There is a marked increase in the sulphates and chlorids as compared with the composition of the shale. The calcium, magnesium, and carbonates decrease slightly. The increase is therefore due to the presence of salts of sodium.

TABLE X.—*Soluble salts in the Tertiary ash*

[Results expressed as pounds per 2,000,000 of material]

Field No.	Location of sample.	Calcium (Ca).	Magnesium (Mg).	Carbonic acid (CO_3).	Sulphuric acid (SO_4).	Chlorin (Cl).
41	Kings Meadow, Utah	26,704	1,494	920	4,181	217,640
42	.....do.....	7,538	1,346	640	2,774	136,840
222	Millburn, Wyo.	5,133	856	640	37,828	709
298	Myton, Utah	7,619	944	640	184,040	Trace.
40	Sigurd, Utah	2,566	843	580	1,679	4,572
217	Millburn, Wyo	7,456	962	840	156,000	1,417
309	Utahn, Utah	2,326	1,223	960	147,120	57
46	Richfield, Utah	1,844	716	320	4,782	284
218	Millburn, Wyo	7,218	1,136	800	178,720	227
38	Richfield, Utah	1,845	681	760	2,206	5,672
1	Nephi, Utah	602	None.	2,100	1,465	26,664
3	.....do.....	641	...do ..	1,220	6,103	993
8	.....do.....	1,443	...do ..	420	2,269	14,320
2	.....do.....	400	...do ..	640	255	None.

As an average, there are 1,107 pounds of calcium bicarbonate, 15,017 pounds of calcium sulphate, 3,665 pounds of magnesium sulphate, 59,595 pounds of sodium sulphate, 11,315 pounds of sodium chlorid, and 4,715 pounds of sodium nitrate—that is, 4.77 per cent of the ashy material are soluble in water. The predominating salt is sodium sulphate, over 30 per cent consisting of this material. The salt next present in greatest quantity is calcium sulphate closely followed by sodium chlorid. As an average, the amount of nitric nitrogen in the shale is 280 parts per million, while the amount of chlorin is 4,603, the ratio being 1 to 16.9. The ash which is the result of concentration of salts on the surface of the shale contains 390 parts per million of nitric nitrogen and 6,597 parts per million of chlorin, the ratio of which is likewise 1 to 16.9.

The soluble salts present in the virgin alkali collected in the undisturbed condition in the hills consists largely of the chlorid and sulphate of sodium, with appreciable quantities of calcium and magnesium sul-

phate. The results obtained on analysis are recorded in Table XI as pounds per 2,000,000 of material. The alkali salts near Myton (sample 301) consist in places largely of the sulphate of sodium. This contains 943 pounds of calcium bicarbonate, 26,435 pounds of calcium sulphate, 3,495 pounds of magnesium sulphate, 847,482 pounds of sodium sulphate, 2,890 pounds of sodium chlorid, and 113 pounds of sodium nitrate—that is, a total of 44 per cent of this alkali material is soluble in water, and the soluble material is 96 per cent pure sodium sulphate. There are nearly 2 per cent of calcium sulphate, with small amounts of magnesium sulphate, sodium chlorid, and sodium nitrate.

TABLE XI.—*Soluble salts in alkali of Tertiary origin*

[Results expressed as pounds per 2,000,000 of material]

Field No.	Location of sample.	Calcium (Ca).	Magnesium (Mg).	Carbonic acid (CO_3).	Sulphuric acid (SO_4).	Chlorin (Cl).
303	Myton, Utah	8,692	874	933	227,800	899
221	Millburn, Wyo	28,232	7,129	27,200	274,400	12,760
298	Myton, Utah	7,699	943	640	184,040	Trace.
234	Lyman, Wyo	6,015	297	1,080	125,600	1,843
204	Millburn, Wyo	24,060	3,705	2,160	74,996	3,120
243	Superior, Wyo	5,372	42,304	920	16,832	2,556
311	Utahn, Utah	1,203	1,170	14,600	261,360	993
53	Grass Valley, Utah	25,344	27,592	2,000	275,940	25,096
47	Glenwood, Utah	4,332	367	480	8,724	330,720
237	Lyman, Wyo	6,176	769	800	242,360	4,112
301	Myton, Utah	8,019	699	1,840	586,400	170
302	do	6,576	436	560	180,320	85
52	Greenwich, Utah	19,488	4,158	800	117,760	19,000
230	Lyman, Wyo	7,136	822	1,080	77,296	3,630
206	Millburn, Wyo	19,728	11,978	3,480	258,040	13,328
51	Greenwich, Utah	1,604	506	680	10,024	425
11	Nephi, Utah	481	None.	3,320	3,058	12,478
227	Lyman, Wyo	7,779	1,957	2,440	303,760	24,712
Average	Tertiary	10,180	7,479	2,815	187,618	24,718

As an average of all the samples collected, the proportion is not so extreme as this. There are 3,800 pounds of calcium bicarbonate, 31,280 pounds of calcium sulphate, 37,380 pounds of magnesium sulphate, 194,400 pounds of sodium sulphate, 142,020 pounds of sodium chlorid, and 420 pounds of sodium nitrate.

The soluble-salt content of the clay is recorded in Table XII. There is a marked individual variation in the results from the clay. Samples 4, 5, and 12 represent the clay lying immediately above the important salt deposits at Nephi and are really good samples of impure rock salt. Averages of the Tertiary clay, which includes these samples, therefore mean very little. In some individual samples the magnesium salts are entirely absent. Carbonates and sulphates of calcium are always present. With the exception of two cases, chlorin is always present.

TABLE XII.—*Soluble salts in clay and soil in place of Tertiary origin*

[Results expressed as pounds per 2,000,000 of material]

Field No.	Location of samples.	Calcium (Ca).	Magnesium (Mg).	Carbonic acid (CO_3).	Sulphuric acid (SO_4).	Chlorin (Cl).
12	Nephi, Utah	7,540	None.	300	35,440	1,172 000
4	do	11,028	None.	280	23,872	925,900
231	Lyman, Wyo.	10,272	1,757	1,400	135,240	13,048
14	Nephi, Utah	24,700	None.	480	61,760	567
216	Millburn, Wyo.	401	367	1,600	9,296	Trace.
235	Lyman, Wyo.	2,724	926	1,000	25,760	425
19	Fountain Green, Utah	600	None.	600	3,654	None.
20	Richfield, Utah	11,388	825	280	33,392	1,205
228	Lyman, Wyo.	3,047	1,607	960	110,400	142
17	Nephi, Utah	842	None.	620	971	1,630
13	do	1,604	None.	720	1,201	10,998
7	do	802	None.	1,160	2,057	17,725
6	do	3,088	1,153	400	608	22,476
207	Millburn, Wyo.	5,856	1,573	720	19,918	992
5	Nephi, Utah	5,614	None.	400	1,448	104,280
54	Grass Valley, Utah	10,708	930	260	29,880	None.
Average.	Tertiary	6,263	571	699	30,880	141,961

The results for the analysis of the sandstone, shale, alkali, and ash of the Jurassic are all recorded in Table XIII. One very significant fact is the low results for water-soluble salts in the sandstone and shale. Another is the fact that only the carbonates, chlorids, sulphates, and nitrates of calcium and magnesium are present. Salts of sodium are absent or present only in very small quantities.

Thus, in the sandstone there are, as an average, 874 pounds of calcium bicarbonate; 5,634 pounds of calcium sulphate, 1,156 pounds of calcium chlorid, 2,600 pounds of magnesium chlorid, and 1,980 pounds of sodium nitrate per 2,000,000 pounds of material. There is 0.607 per cent of soluble material, nearly 50 per cent of which is calcium sulphate.

Likewise, in the shales the salts consist largely of the carbonates, sulphates, and chlorids of calcium and magnesium. There is 500 pounds of calcium bicarbonate, 3,182 pounds of calcium sulphate, 2,430 pounds of magnesium sulphate, 855 pounds of magnesium chlorid, and 98 pounds of sodium nitrate. There is 0.30 per cent of soluble salts in the shales, over 50 per cent of these salts being calcium sulphate.

The alkali material is not widely prevalent in the cultivated soil derived from the Jurassic either in the native virgin or cultivated soils The alkali here reported consists of the leaching from beneath the sandstone. Occasionally the underpart of the sandstone decays very rapidly, and white incrustations are deposited immediately beneath the rotten sandstone. One sample, No. 259, of this material was collected. Another sample, No. 288, consisting of crystalline material, was also collected. The alkali accumulations, or niter spots, prevalent in the soils derived from other geologic formations, were not observed by us in the Jurassic. Three samples of the ashy material were collected from beneath the

rotten sandstone or immediately above the gypsum deposits. Both the alkali and ash materials consist largely of the sulphates of calcium, magnesium, and sodium, with small amounts of calcium bicarbonate, sodium chlorid, and sodium nitrate.

TABLE XIII.—*Soluble salts in Jurassic material*

[Results expressed as pounds per 2,000,000 of material]

Field No.	Location of samples.	Calcium (Ca).	Magnesium (Mg).	Carbonic acid (CO_3).	Sulphuric acid (SO_4).	Chlorin (Cl).
SANDSTONE						
283	Vernal, Utah	3,048	1,485	1,040	809	2,836
25	Richfield, Utah	3,248	None.	360	8,402	15,668
250	Moab, Utah	3,929	611	440	10,108	None.
254	do	962	672	816	329	284
255	do	1,443	515	640	2,107	425
251	do	1,684	699	480	2,535	284
253	do	1,524	637	760	3,885	Trace.
Average	Jurassic	2,263	660	648	4,025	2,785
SHALES						
284	Vernal, Utah	834	262	776	4,246	Trace.
24	Richfield, Utah	5,213	7,224	1,040	31,176	3,048
285	Vernal, Utah	1,925	236	1,132	1,546	284
23	Richfield, Utah	1,165	2,053	380	1,893	2,978
10	Nephi, Utah	1,524	None.	380	3,045	71
Average	Jurassic	1,066	997	370	4,190	638
ALKALI						
259	Moab, Utah	1,283	786	840	12,412	3,686
288	Vernal, Utah	15,558	2,726	1,120	404,480	Trace.
Average	Utah	8,421	1,756	980	208,446	1,843
ASH						
252	Moab, Utah	7,940	26,072	960	217,960	4,960
293	Vernal, Utah	2,887	3,949	320	54,456	283
135	Emery, Utah	401	384	920	14,152	567
Average	Jurassic	3,742	10,135	733	85,522	1,937

Probably the most significant fact is the extremely small quantity of alkali salts present in the country rock of the Quaternary period collected from the Cache Valley, Utah. The soils of this area are very productive and for the most part are largely free from alkali, especially as compared with the soils of the other areas studied. Large alkali areas such as occur elsewhere in the far West are unknown in this section. Nineteen representative samples of the country rock from this district were collected. The amount of soluble salts were so small that it was not thought worth while to make an analysis for the individual salts

and only the results for total salts are therefore available. These results are recorded in Table XIV. The amount of material is very small and as an average is 0.24 per cent.

TABLE XIV.—*Soluble salts in Quaternary material from Cache Valley, Utah*

[Results expressed as pounds per 2,000,000 of material]

Sample No.	158	167	165	164	166	161	149	136	160
Total salts	3,360	880	3,600	7,200	3,920	3,440	11,360	4,560	4,160

Sample No.	162	172	176	175	153	154	155	150	162	168
Total salts	2,240	6,800	3,360	6,400	2,160	8,800	16,880	3,600	3,280	2,080

Average 4,904 pounds, or 0.24 per cent of total salts.

Considerable concentration must take place over large areas to cause the production of alkali soils such as occur elsewhere. It is not surprising that there is not more alkali in the Cache Valley.

SOLUBLE SALTS IN THE GYPSUM DEPOSITS

The State of Utah contains enormous deposits of gypsum. These deposits are not peculiar to any single geological area or locality. They are widely distributed throughout the State. Fourteen samples of this gypsum were collected and analyzed. The results are recorded in Table XV. As would be expected, the soluble material consists largely of the sulphates of calcium. As an average, 2.72 per cent are soluble in water, consisting almost entirely of calcium sulphate, 96 per cent of the total soluble being gypsum. As an average, there are 892 pounds of calcium bicarbonate, 52,500 pounds of calcium sulphate, and 1,152 pounds of magnesium chlorid.

TABLE XV—*Soluble salts in the gypsum deposits*

[Results expressed as pounds per 2,000,000 of material]

Field No.	Location of samples.	Geologic formation.	Calcium (Ca).	Magnesium (Mg).	Carbonic acid (CO_3).	Sulphuric acid (SO_4).	Chlorin (Cl).
247	Moab, Utah	Jurassic	22,856	11,096	1,440	9,536	8,080
34	Sigurd, Utah	Tertiary	24,384	576	320	71,360	284
257	Moab, Utah	Jurassic	4,009	262	640	18,764	284
249	do	do	13,552	1,031	1,280	31,408	Trace.
142	Emery, Utah	Cretaceous	320	582	1,840	19,750	284
246	Moab, Utah	Jurassic	23,096	943	1,000	55,248	425
138	Emery, Utah	Cretaceous	22,376	681	160	56,464	Trace.
258	Moab, Utah	Jurassic	1,004	489	680	5,300	None.
139	Emery, Utah	Cretaceous	22,376	751	200	57,216	284
21	Richfield, Utah	Tertiary	11,268	None.	280	31,672	283
35	Sigurd, Utah	do	24,384	192	440	61,552	Trace.
37	do	do	11,628	319	180	25,876	Do.
16	Nephi, Utah	do	12,188	None.	360	27,840	355
15	do	do	24,944	do	4,400	59,920	1,702
	Average		15,670	1,209	661	36,723	856

TABLE XVI—*Soluble salts in miscellaneous soil-forming material*

[Results expressed as pounds per 2,000,000 of material.]

Field No.	Location of sample.	Calcium (Ca).	Magnesium (Mg).	Carbonic acid (CO_3).	Sulphuric acid (SO_4).	Chlorin (Cl).
58	Greenwich, Utah	8,420	None.	640	21,724	851
226	Lyman, Wyo	None.	908	2,000	4,806	6,019
240	Superior, Wyo	962	978	880	1,119	567
219	Lyman, Wyo	1,925	2,237	2,160	2,160	851
267	Dragon, Colo	561	716	1,200	691	None.
239	Superior, Wyo	962	1,160	1,200	1,086	354
209	Lyman, Wyo	1,090	734	840	2,996	284
27	Nephi, Utah	1,042	1,484	600	8,104	7,232
58	Greenwich, Utah	8,420	None.	640	21,724	851
226	Lyman, Wyo	None.	908	2,000	4,806	6,019
240	Superior, Wyo	962	978	880	1,119	567
219	Lyman, Wyo	1,925	2,237	2,160	2,160	851
267	Dragon, Colo	561	716	1,200	691	None.
239	Superior, Wyo	962	1,160	1,200	1,086	354
209	Lyman, Wyo	1,090	734	840	2,996	284
27	Nephi, Utah	1,042	1,484	600	8,104	7,232
28	Richfield, Utah	2,406	2,140	2,000	40,480	4,688
29	do	2,005	2,796	2,200	29,722	2,836
220	Lyman, Wyo	1,283	891	1,000	6,056	284
26	Richfield, Utah	240	262	680	3,605	5,530
49	Greenwich, Utah	1,283	559	480	1,251	709
50	do	1,043	288	380	2,271	425
18	Fountain Green, Utah	441	None.	310	567	1,205
45	Greenwood, Utah	4,772	2,324	360	30,480	1,772
266	Dragon, Utah	641	699	1,200	691	None.
Average		1,710	1,099	1,068	9,223	1,977

In Table XVI are recorded the results of some analyses of material which do not readily fit into the classification previously recorded. Some of these samples contain appreciable quantities of soluble salts, while others do not contain material quantities. Thus, No. 267 and 266, representatives of the limestone deposits above the Cretaceous sandstone, contain only nominal amounts of soluble salts and are comparable with the country of the Quaternary deposits of Cache Valley. Other samples, such as No. 45 and 28, which possibly ought to be classified with the Tertiary material, contain appreciable quantities of alkali salts.

As an average of all determinations, this material contains 1,444 pounds of calcium bicarbonate, 4,535 pounds of calcium sulphate, 5,495 pounds of magnesium sulphate, 2,438 pounds of sodium sulphate, and 3,360 pounds of sodium chlorid—that is, 0.86 per cent of the material is soluble in water.

SUMMARY OF RESULTS

The results of these investigations show a marked amount of water-soluble salts or alkali in the undistributed country rock with local accumulation wherever the movement of the underground water has

caused a local concentration by seepage through the rock and deposition by evaporation. There is a marked variation in the amount of salts occurring in the country rock in any given geological series. But uniformly high results have been obtained at widely separated sections of the country, such as those found at Grand Junction, Colo., Emery and Vernal, Utah, and Lyman, Wyo. There is a marked concentration of nitrates and alkali in the ashlike and alkali deposits in the uncultivated areas.

The following summary (Table XVII) shows the average alkali material found in the country rock.

TABLE XVII.—*Average alkali material in country rock*

CRETACEOUS MATERIAL

[Results expressed as pounds per 2,000,000]

Material.	Calcium.		Magnesium.			Sodium.			Total.
	Bicarbonate.	Sulphate.	Sulphate.	Chlorid.	Nitrate.	Sulphate.	Chlorid.	Nitrate.	
									Per cent.
Sandstone	983	16,469	3,922	985	1,961	.....	.....	.....	1.21
Shale	993	15,738	10,780	.....	.....	13,036	1,148	2,079	2.19
Clay	1,021	18,091	7,780	.....	.....	9,411	1,999	775	1.75
Ash	1,073	21,743	14,035	.....	.....	99,910	2,380	3,623	7.13
Alkali	3,419	35,666	127,235	.....	.....	152,682	17,665	5,492	17.1

TERTIARY MATERIAL

Sandstone	1,904	2,621	1,175	1,416	2,530	.....	.....	.....	.45
Shale	1,764	23,320	2,350	2,352	.....	.....	4,826	3,362	1.90
Ash	1,107	15,017	3,665	.....	.....	59,595	11,315	4,715	4.77
Alkali	3,800	31,280	37,380	.....	.....	194,400	142,020	420	20.46

JURASSIC MATERIAL

Sandstone[a]	874	5,634	.....	2,600	.....	.....	.....	1,980	.60
Shale	500	3,182	2,430	855	.....	.....	.....	98	.30

[a] Also 1,156 pounds of calcium chlorid present.

The summary brings clearly to mind the fact that in a widely disseminated form there is in the shales and sandstones of the Cretaceous and Tertiary of Utah, Colorado, and Wyoming enormous deposits of soluble salts consisting of the sulphates, chlorids, nitrates, and bicarbonates of calcium, magnesium, and sodium. In certain local areas these salts become concentrated so as to produce native alkali, or "niter spots," by the movement of the underground water without the instrumentality of the irrigation ditch. Wherever the shale is highly impregnated with the salts the evaporation of the water deposits the alkali salts on the surface in the form of an ashlike powder.

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EFFECT OF PARAFFIN ON THE ACCUMULATION OF AMMONIA AND NITRATES IN THE SOIL

By P. L. Gainey,

Soil Bacteriologist, Kansas Agricultural Experiment Station

INTRODUCTION

For many years paraffin has found a wide use in the study of soil biology, plant physiology, soil fertility, mycology, and kindred subjects. Its peculiar physical properties, chemical inactivity, and comparative resistance to biological activity render it especially adapted to a variety of uses in these sciences. In many instances it is capable of rendering very valuable service. It is the purpose of this preliminary report, however, to call attention to certain dangers attendant upon such widespread use.

Perhaps the widest use of paraffin in the studies previously mentioned has been in the "paraffin wire-basket method" of studying soil fertility, a method recommended by the Bureau of Soils, United States Department of Agriculture (1) [1] and in a large number of variations from this method where paraffin is used to accomplish the same end. The object of its use in such instances has been in most cases to surround the medium (soil or solution) with a substance of a very inactive nature, impervious to both water and air. The principle of the above method as recommended by the Bureau of Soils and later adapted to physiological as well as fertility studies, consisted in substituting wire baskets coated with paraffin for the metallic or earthenware containers more commonly employed for such purposes.

According to Whitney and Cameron (9, p. 38),

> this form of basket has been eminently satisfactory.

Hoffmann (5) also has recommended the use of a paraffin block as a means of supporting seedlings growing in cultural solutions. Various modifications of this method have found use in a number of laboratories.

The Michigan Experiment Station (2) has made rather extensive use of paraffin oil in the separation of a soil solution to be used subsequently in chemical and physiological investigations of soil-fertility problems. Other instances are recorded in which the use of paraffin has been recommended in biological and cultural studies.

EXPERIMENTAL WORK

In experimental work to ascertain whether aeration can take place sufficiently in an uncultivated soil to maintain aerobic conditions in the subsurface, it became necessary to use a substance of a physical nature similar to paraffin. The commercial Parowax, prepared for the trade by

[1] Reference is made by number to "Literature cited," pp. 363–364.

the Standard Oil Co., was found to be admirably suited physically for this purpose. The method of study consisted in transferring to glass jars solid undisturbed cores of soil 5 inches in diameter and of varying length and in preventing aeration except through the normal surface. Subsequent measurements of the nitrate-nitrogen content at varying depths were made. To prevent aeration on the sides and bottom, melted Parowax was poured around the column of soil until it filled the space between the soil and jar, thus very effectually preventing the access of oxygen except from surface. A large number of experiments of this nature, in which aeration was varied by drawing a current of air through the column and by varying the physical condition of the column of soil, were carefully planned and executed.

In all instances where the Parowax came in intimate contact with the soil the accumulation of nitrate nitrogen, in spite of the fact that the other conditions favored nitrification, was so irregular and so unexpected that the results were absolutely inexplicable. The only outstanding fact to be gathered from the mass of data accumulated from the experiments was the apparent inhibitory effect the Parowax exerted upon the accumulation of nitrate nitrogen.

It was thought possible that the Parowax contained something toxic to the nitrifying organisms, but the substitution of paraffin prepared by Sargent & Co. for scientific purposes (M. P. 50°) did not alter the results. Studies were therefore initiated to ascertain, qualitatively and quantitatively, just what effect such substances produced upon biological activity in general and particularly upon the accumulation of nitrate nitrogen in the soil. In Tables I, II, and III are given data secured from typical experiments.

In all these experiments a soil possessing a vigorous ammonia and nitrate-forming flora was used in 100-gm. samples. From the results of the controls, in which no paraffin was used, the activity of the flora is shown to be very vigorous. The containers in all experiments were 500-c. c. wide-mouthed cotton-plugged bottles. Calcium carbonate was added to some samples and not to others. Samples were incubated with no addition of nitrogen, with nitrogen in the form of ammonium sulphate, and with nitrogen in the form of cottonseed meal. Incubation was in all cases at room temperature, and the moisture loss was replaced at frequent intervals. Where bottles are spoken of as being "Parowaxed" or "paraffined" the hot, melted substance was poured into the bottle, which was tilted so that the liquid would come in contact with all the inner surface, and the excess poured off. Where paraffin and Parowax were added direct to the soil, they were in the form of thin shavings made by scraping a cold bar of the solid substance. Paraffin oil was added by measuring from a pipette the desired quantity. After all additions were made and thoroughly mixed in, the moisture content of the soil was adjusted to optimum.

Nitrate nitrogen was determined colorimetrically and is reported as milligrams of NO_3 per 100 gm. of soil. Ammonia nitrogen was determined by the magnesium-oxid distillation method and reported as

milligrams of nitrogen per 100 gm. of soil. "Active nitrogen" represents the total quantity of nitrogen present both as NO_3 and NH_3. Ammonia was tested qualitatively with Nessler's reagent. Where it is reported as a "trace," only slight color resulted from the test. Where it is reported as "good," a strong yellow color was developed. Where it is reported as "abundant," a heavy brick-red precipitate was formed when the reagent was added to the clear solution.

RESULTS OF EXPERIMENTATION

The results presented in Tables I, II, and III are certainly very striking and show conclusively that paraffin can not be employed in investigations such as are mentioned earlier in this paper, unless the microbial flora is absolutely under control as regards the species present in the biological pabulum.

When nitrogen was not added, regardless of whether calcium carbonate was added, the presence of paraffin in the three forms here used completely inhibited the accumulation of both ammonia and nitrate nitrogen. Not only did it prevent further accumulations of nitrate nitrogen but actually caused all that was present at the beginning of the experiments to disappear. The effect was maintained for the longest period here recorded, 13 weeks, and similar results have been observed for even longer periods of incubation. The above relations held true whether the paraffin was intimately mixed into the soil or simply lined the inner wall of the container. In the latter case the quantity of paraffin actually coming in contact with the soil was rather limited.

When cottonseed meal was added as a source of nitrogen, vigorous ammonia and nitrate formation took place in the presence of paraffin. Owing to the very rapid subsequent disappearance of both ammonia and nitrate nitrogen, their formation is sometimes not apparent, and it is impossible to say whether such formation was equally as rapid as in the absence of paraffin. In no case after the 2-week analysis does the quantity of ammonia or nitrate nitrogen, where Parowax or paraffin was present, even approach the quantity in the controls. Differences in favor of the controls are evident even at the end of one week, and with both these forms of paraffin the active nitrogen (NO_3+NH_3) soon falls to a mere trace. Where paraffin oil was added, the results are somewhat different. During the early stages of incubation the inhibitory effect upon the accumulation of both forms of nitrogen is more marked than with other forms of paraffin. In the case of the oil the effect appears to be quite largely an inhibition of formation rather than a disappearance of ammonia and nitrate nitrogen, for, as incubation progresses, the quantity of active nitrogen approaches very closely that present in the controls. The decreased accumulation of both forms of nitrogen in the presence of Parowax and paraffin is more marked where they are mixed into the soil than where only surrounding it.

TABLE I.—*Effect of paraffin and Parowax upon the accumulation of nitrate and ammonia nitrogen in soil; with calcium carbonate*

[Results expressed as milligrams of NO_3 or milligrams of nitrogen as NH_3 per 100-gm. of soil]

No.	Treatment.	Quantity of nitrogen added.	2 weeks' incubation.		4 weeks' incubation.		12 weeks' incubation.	
			NO_3.	NH_3.[a]	NO_3.	NH_3.[a]	NO_3.	NH_3.[a]
1	None	None	5.3	Good reaction.	5.0	Good reaction.	7.0	Good reaction.
2	Calcium carbonate, 0.5 gm	do	5.8	do	6.1	do	20.4	Trace.
3	Bottle paraffined	do	[b]T.	Trace	T.	Trace	T.	Do.
4	Calcium carbonate, 0.5 gm.; bottle paraffined	do	T.	do	T.	do	T.	Do.
5	Bottle Parowaxed	do	T.	do	T.	do	T.	Do.
6	Calcium carbonate, 0.5 gm.; bottle Parowaxed	do	T.	do	T.	do	T.	Do.
7	Paraffin, 2 gm	do	T.	do	T.	do	T.	Do.
8	Calcium carbonate, 0.5 gm.; paraffin, 2 gm	do	T.	do	T.	do	T.	Do.
9	Parowax, 2 gm	do	T.	do	T.	do	T.	Do.
10	Calcium carbonate, 0.5 gm.; Parowax, 2 gm	do	T.	do	T.	do	T.	Do.
11	Calcium carbonate, 0.5 gm	30 mgm. as ammonium sulphate	5.7	Abundant	6.0	Abundant	100.0	Do.
12	Calcium carbonate, 0.5 gm.; bottle paraffined	do	5.3	do	4.1	do	41.0	Do.
13	Calcium carbonate, 0.5 gm.; bottle Parowaxed	do	5.1	do	2.2	do	45.0	Good reaction.
14	Calcium carbonate, 0.5 gm.; paraffin, 2 gm	do	5.0	do	5.0	do	28.1	Trace.
15	Calcium carbonate, 0.5 gm.; Parowax, 2 gm	do	4.5	do	4.5	do	37.5	Do.
16	Calcium carbonate, 0.5 gm	30 mgm. as cottonseed meal	1.9	do	2.2	do	112.5	Do.
17	Calcium carbonate, 0.5 gm.; bottle paraffined	do	.8	do	0.0	do	0.0	Good reaction.
18	Calcium carbonate, 0.5 gm.; bottle Parowaxed	do	.3	do	0.0	do		
19	Calcium carbonate, 0.5 gm.; paraffin, 2 gm	do	T.	do	0.0	Good reaction.	0.0	Trace.
20	Calcium carbonate, 0.5 gm.; Parowax, 2 gm	do	1.2	do	0.0	do	0.0	Do.

[a] NH_3 tested qualitatively.

[b] T. = trace.

TABLE II.—*Effect of Parowax and paraffin upon the accumulation of nitrate and ammonia nitrogen in soil*

[Results expressed as milligrams of NO_3 or milligrams of nitrogen as NH_3 per 100 gm. of soil]

No.	Treatment.	Quantity of nitrogen added.	2 weeks' incubation.		5 weeks' incubation.		13 weeks' incubation.		NH_3 (quantitative).	Active nitrogen.[a]
			NO_3.	NH_3 (qualitative).	NO_3.	NH_3 (qualitative).	NO_3.	NH_3 (qualitative).		
1	None	None	3.7	Trace	6.0	Trace	6.4	Trace	1.23	2.67
2	Bottle Parowaxed	do	0.0	do	0.0	do	Tr.	do	[b] 1.23	1.23
3	Bottle paraffined	do	0.0	do	0.0	do	0.0	do	[b] 1.23	1.23
4	Parowax, 2 gm	do	0.0	do	0.0	do	0.0	do	[b] 1.23	1.23
5	Paraffin, 2 gm	do	0.0	do	0.0	do	0.0	do	[b] 1.23	1.23
6	None	30 mgm. as ammonium sulphate	12.8	Abundant	28.2	Abundant	45.0	Abundant	14.43	24.55
7	Bottle Parowaxed	do	11.4	do	22.5	do	28.2	do	9.48	15.82
8	Bottle paraffined	do	11.4	do	26.4	do	32.1	do	9.00	16.22
9	Parowax, 2 gm	do	11.4	do	15.8	do	25.0	do	9.08	14.70
10	Paraffin, 2 gm	do	9.0	do	12.8	do	13.5	do	4.11	7.15
11	None	30 mgm. as cottonseed meal	22.5	do	75.0	Good reaction	53.1	do	4.53	16.48
12	Bottle Parowaxed	do	15.0	do	22.5	Trace	18.0	Trace	1.65	5.70
13	Bottle paraffined	do	18.0	do	56.2	Good reaction	22.5	do	[b] 1.65	6.71
14	Parowax, 2 gm	do	9.6	Good reaction	Tr.	Trace	Tr.	do	[b] 1.65	1.65
15	Paraffin, 2 gm	do	7.7	do	0.0	do	0.0	do	[b] 1.65	1.65

[a] Active nitrogen is NO_3 nitrogen+NH_3 nitrogen.

[b] Figures estimated from other analyses showing similar qualitative results.

TABLE III.—*Effect of paraffin, Parowax, and paraffin oil upon the accumulation of nitrate and ammonia nitrogen in soil*

[Results expressed as milligrams of NO_3 or miligrams of nitrogen as NH_3 per 100 gm. of soil]

No.	Treatment.	Quantity of nitrogen added.	1 week incubation.				2 weeks' incubation.			
			NO_3	NH_3		Active nitrogen.	NO_3	NH_3		Active nitrogen.
				Qualitative.	Quantitative.			Qualitative.	Quantitative.	
1	None	None	2.8	Trace			4.6	Good reaction		
2	Paraffin, 2 gm	do	2.8	do			1.1	Trace		
3	Parowax, 2 gm	do	2.4				0.5	do		
4	Paraffin oil, 2 gm	do	1.2	Trace			Trace.	do		
5	None	50 mgm. as ammonium sulphate	4.6	Abundant			13.1	Abundant		
6	Paraffin, 2 gm	do	4.6	do			14.1	do		
7	Parowax, 2 gm	do	4.8	do			15.2	do		
8	Paraffin oil, 2 gm	do	3.8	do			12.0	do		
9	None	50 mgm. as cottonseed meal	4.1	do	23.83	24.75	15.0	do	26.77	30.15
10	Paraffin, 2 gm	do	3.5	do	18.11	18.90	13.3	do	16.07	19.06
11	Parowax, 2 gm	do	3.5	do	20.39	21.17	14.1	do	24.64	27.81
12	Paraffin oil, 2 gm	do	2.4	do	15.25	15.79	10.0	do	23.03	25.28

No.	Treatment.	Quantity of nitrogen added.	4 weeks' incubation.				6 weeks' incubation.				8 weeks' incubation.			
			NO_3	NH_3		Active nitrogen.	NO_3	NH_3		Active nitrogen.	NO_3	NH_3		Active nitrogen.
				Qualitative.	Quantitative.			Qualitative.	Quantitative.			Qualitative.	Quantitative.	
1	None	None	6.7	Trace			5.5	Trace	1.16	2.40	10.2	Trace		2.3
2	Paraffin, 2 gm	do	1.8	do			Trace.	do	1.16	1.16	Trace.	do		
3	Parowax, 2 gm	do	1.8	do			Trace.	do	1.16	1.16	Trace.	do		
4	Paraffin oil, 2 gm	do	2.0	do			Trace.	do	[a]1.16	1.16	Trace.	do		
5	None	50 mgm. as ammonium sulphate.	90.0	Abundant			120.0	Good reaction	2.80	29.80	180.0	do		40.5
6	Paraffin, 2 gm	do	48.6	do			60.0	Abundant	6.60	20.10	105.0	do		23.6
7	Parowax, 2 gm	do	52.8	do			72.0	do	4.46	20.66	121.0	do		27.2
8	Paraffin oil, 2 gm	do	50.7	do			100.0	do	9.40	31.90	180.0	do		40.5
9	None	50 mgm. as cottonseed meal.	100.0	Good reaction.	6.10	28.60	90.0	Trace	[a]2.48	22.73	121.0	do		27.2
10	Paraffin, 2 gm	do	14.0	Trace	2.64	5.79	Trace.	do	[a]2.48	2.48	Trace.	do		
11	Parowax, 2 gm	do	40.5	do	2.06	11.17	Trace.	do	2.48	2.48	Trace.	do		
12	Paraffin oil, 2 gm	do	56.0	Abundant	15.00	27.60	69.0	do	[a]2.48	18.00	106.0	do		23.8

[a] Estimated.

When ammonium sulphate was added to the soil either with or without calcium carbonate, all three forms of paraffin exerted a very marked effect upon the accumulation of nitrate nitrogen. The decreased accumulation of nitrate nitrogen was not so evident during the early stages of incubation except with paraffin oil. With the oil the effect again seems to be to retard nitrification, the quantity of active nitrogen approaching very closely that in the controls. Parowax and paraffin, however, not only decrease the accumulation of nitrate nitrogen but also bring about a large reduction in the quantity of active nitrogen. The reduction in active nitrogen occasioned by the various forms of paraffin is not nearly so rapid where ammonium sulphate was added as where nitrogen in the form of cottonseed meal was added. This is probably due to the food elements other than nitrogen contained in the cottonseed meal.

In the experiments thus far given the mass of soil used was only 100 gm. In order to ascertain whether coating the containing vessel with paraffin would exercise an appreciable effect upon NO_3 accumulation if the volume of soil were larger, the following experiments were carried out. The inside of a glass jar 5 inches in diameter was coated with paraffin, another was coated with Parowax, and a third was left untreated. The jars were all filled with loose soil containing optimum moisture and calcium carbonate. After seven weeks of incubation the soil of each jar was mixed and analyzed for NO_3. The following quantities, expressed as milligrams of NO_3 per 100 gm. of soil, were found to be present: Untreated jar, 7.1 mgm.; paraffined jar, trace; Parowaxed jar, trace.

At the same time a 2-gallon earthenware jar 8¼ inches in diameter coated on the inside with paraffin and another untreated were filled with the same soil and incubated the same length of time. Upon analysis a central column of soil 2¼ inches in diameter was removed from each jar and analyzed separately. The milligrams of NO_3 per 100 gm. of soil from the central core and from the remaining soil in each jar were as follows:

	Center.	Remainder.
Untreated jar	7.6	7.8
Paraffined jar	5.3	1.2

The closest that the central column came to the surrounding paraffin was 3 inches, yet the paraffin caused a reduction of approximately one-third in the accumulation of nitrate nitrogen. It is evident, therefore, that the effect of paraffin upon NO_3 accumulation can be exerted over an appreciable distance. These experiments show that no ordinary sized container used for cultural purposes can be protected with a coating of paraffin, as in these experiments, without the available nitrogen content throughout the whole mass of soil being affected.

DISCUSSION OF RESULTS

To what is this very marked effect of paraffin upon the accumulation of ammonia and nitrate nitrogen to be ascribed? Where the major differences are observed, the evidence does not seem to support the view that it is an inhibitory effect exerted upon the ammonifying and nitrifying organisms. There is evidence that such an effect may occur to a slight extent in some instances, but the very large actual disappearance of nitrate and ammonia nitrogen, one time present, certainly can not be ascribed to such a phenomenon. Since the experimental conditions were strictly aerobic, as the nitrification in controls and sometimes in treated samples will show, they would tend to eliminate denitrifying processes. The only other possibility lies in an actual metabolic consumption by organisms stimulated by the presence of paraffin. It is rather difficult to conceive of the consumption of such large quantities in this manner in such a short period of time, unless one has observed such cultures.

Parallel with the disappearance of active nitrogen, there has also been a disappearance of paraffin and an enormous development of certain species of fungi. This growth of saprophytic fungi was so abundant where ammonium sulphate and cottonseed meal were added that at the end of two to four weeks the cultures appeared to be almost solid masses of white hyphæ which later developed almost all varieties of color. In the absence of added nitrogen, while the growth was not sufficient to be macroscopically visible, other physical characteristics showed growth to be abundant.

Rahn (6) a number of years ago called attention to the presence in soil of a species of Penicillium capable of utilizing paraffin in its metabolism when grown in cultural solutions containing paraffin as the only organic constituent. Later Söhngen (7) isolated and studied from soils and other sources a number of species of bacteria capable of utilizing paraffin under similar conditions. It is not unreasonable, therefore, to assume that the enormous growth of fungi observed where paraffin was added utilized this as a source of carbon and energy; also that the active nitrogen observed to disappear was used as source of nitrogen in the metabolism of the fungi. Where no nitrogen was added, available nitrogen soon became the limiting factor in fungus growth. Growth under such conditions was accordingly much more limited. So long as nitrogen remained the limiting factor in growth, that present in a form capable of being utilized was consumed as rapidly as it became available. Ammonia and nitrate nitrogen are both readily available to many saprophytic bacteria and fungi; hence, the quantities of these two forms of nitrogen would be kept at a minimum. On the other hand, when ammonia or an organic substance capable of yielding ammonia in large

quantities was added, available nitrogen no longer became the limiting factor in fungus growth. Under such conditions the existence of ammonia or an accumulation of nitrate nitrogen to a limited extent became possible.

The extensive use of paraffin in the "paraffin wire-basket method" of studying soil fertility and in similar studies involving the same principles has been previously mentioned. It might be well to call attention to the extensive comparisons of the manurial requirements as ascertained by this method and in actual field tests conducted by the Rhode Island Station (3, 4, 8). This was probably the most comprehensive test of the reliability of the method ever carried out. As a summary of the results, Hartwell and Pember (4, p. 31) have the following to say:

> The frequent failure of the method to secure at different times similar indications regarding the deficiencies of a given soil, even when carried out in the same manner, is the most discouraging feature concerning the usefulness of the method. The many instances of disagreement between the results of the basket method and those secured in actual field practice render unreliable the indications which the method in its present form affords regarding the manurial requirements, at least of certain soils.

Hartwell and his associates offer no explanation of the anomalous results secured by this method, and, so far as we are aware, no one has explained why so many incorrect indications of manurial requirements were recorded. Wheeler, Brown, and Hogenson (8) do mention in one instance the possibility of denitrification where nitrate nitrogen was added in presence of manure, but attribute this possibility to the manure rather than to the method.

The results in the present paper undoubtedly offer a satisfactory explanation for the failure of the method we were using in the study of aeration in soils. In these results we also have a probable explanation of the failure of the "paraffin wire-basket method" in the hands of the Rhode Island investigators and in other instances where such failures may have been recorded. No doubt where such a stimulation of saprophytic development is brought about, not only will nitrogen but also other food elements required in growth be consumed. These facts must all be taken into consideration when paraffin is used in physiological or cultural experiments involving a mixed culture possibly containing organisms capable of utilizing paraffin in their metabolism. The value and significance of all results heretofore reported as secured under such conditions must also be discounted.

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VOLATILITY OF ORGANIC COMPOUNDS AS AN INDEX OF THE TOXICITY OF THEIR VAPORS TO INSECTS [1]

By WILLIAM MOORE, [2]
Head of Section of Research in Economic Zoology, Minnesota Agricultural Experiment Station

INTRODUCTION

In a previous paper [3] the writer pointed out the relationship between the toxicity of various benzene derivatives and their boiling points, citing the literature. The question arose whether a similar relationship of boiling point and toxicity existed among other volatile organic compounds. Early in the work it was discovered that boiling point was merely a convenient general index of the volatility of the compound and that the real relationship was probably between toxicity and volatility. It was at first thought that this relationship existed only with compounds having an action on lower organisms similar to that of chloroform and ether, but it was soon found to have a wider range of application.

METHOD OF EXPERIMENTATION

In general, the same methods were employed as in the previous work.[3] In order to hasten the rate of diffusion of the vapor throughout the flask, the piece of filter paper, with the chemical to be tested, was suspended in the center of the flask by means of a fine wire. The lead foil covering the stoppers was attacked by some of the acids used in the experiments, making it necessary in these cases to coat the stoppers with collodion. Many of the chemicals produced anesthesia, and, although the flies showed no signs of life, they recovered upon being removed from the flask. A new method was therefore employed in determining the amount of the chemical necessary to kill in 400 minutes. Flasks containing varying quantities of the chemical were started and all were stopped 400 minutes later. These exposed to the smaller doses usually revived; with slightly stronger doses only a partial revival was noticed; while the larger quantities of the chemical resulted in death. In this manner the actual amount necessary to kill in 400 minutes was determined.

In studying the volatility 0.5 c. c. of the liquid was spread over a ground-glass plate and the time necessary for this quantity to evaporate noted. Solids were powdered, and 1 gm. was spread out on the glass to

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[2] The author wishes to express his thanks to Dr. R. A. Gortner and Dr. A. D. Hirschfelder for suggestions as to various chemicals to test and for samples of many of these chemicals, to Dean Frankforter and the School of Chemistry for certain other chemicals, and to S. A. Graham for considerable of the routine work of the investigation.

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evaporate. After a certain period, varying according to the volatility of the compound, the solid was weighed again, the loss in weight being the amount evaporated in that period of time. These data were then reduced to gram-molecules evaporated in 400 minutes.

The insect used in the tests was the housefly (*Musca domestica* L.), reared under natural conditions.

CHEMICALS TESTED

In the selection of the organic compounds to be tested the object was to obtain a series differing widely in their chemical composition and toxicology. Their possible use as insecticides was not considered, since the object of the investigation was to discover the general laws of toxicity of volatile organic compounds to insects.

The chemicals might be conveniently divided into hydrocarbons, esters, acids, ethers, hydrocarbon derivatives containing hydroxyls, aldehydes, ketones, halogens, sulphur or nitrogen, terpenes or terpene derivatives, and alkaloids. The following list is thus divided:

Hydrocarbons:
- Petroleum ether (pentane and hexane).
- Gasoline (mostly heptane).
- Kerosene (mostly nonane and decane).
- Benzene.
- Toluene.
- Xylene.
- Naphthalene.
- Camphene.

Acids:
- Acetic acid.
- Butyric acid.
- Valeric acid.

Aldehydes and ketones:
- Acetone.
- Acetaldehyde.
- Chloral hydrate.
- Brommethylphenylketone.
- Furfural.
- Menthone.

Sulphurs:
- Carbon bisulphid.
- Ethyl mercaptan.
- Allyl isosulphocyanate.
- Thiophene.

Terpenes and their derivatives:
- Camphene.
- Camphor.
- Menthone.
- Menthol.
- Pinene.
- Terpinol.
- Citral.

Terpenes and their derivatives—Contd.
- Eugenol.
- Isoeugenol.
- Geranyl acetate.

Esters:
- Methyl salicylate.
- Ethyl malonate.
- Ethyl acetoacetate.
- Amyl acetate.
- Amyl valerate.
- Propyl acetate.

Ethers:
- Ethyl ether.
- α-Naphthol ethyl ether.

Hydroxyls:
- Methyl alcohol.
- Ethyl alcohol.
- Amyl alcohol.
- Menthol.
- Thymol.

Halogens:
- Chloroform.
- Bromoform.
- Carbon tetrachlorid.
- Chloretone.
- Brometone.
- Ethylene bromid.

Nitrogen:
- Chlorpicrin.
- Amyl nitrite.
- Nitrobenzene.
- Pyridin.

Alkaloids:
- Nicotin.

EXPERIMENTAL RESULTS

Eugenol, isoeugenol, and α-napthol ethyl ether were so slightly volatile that more than 400 minutes were required for the death of the flies;

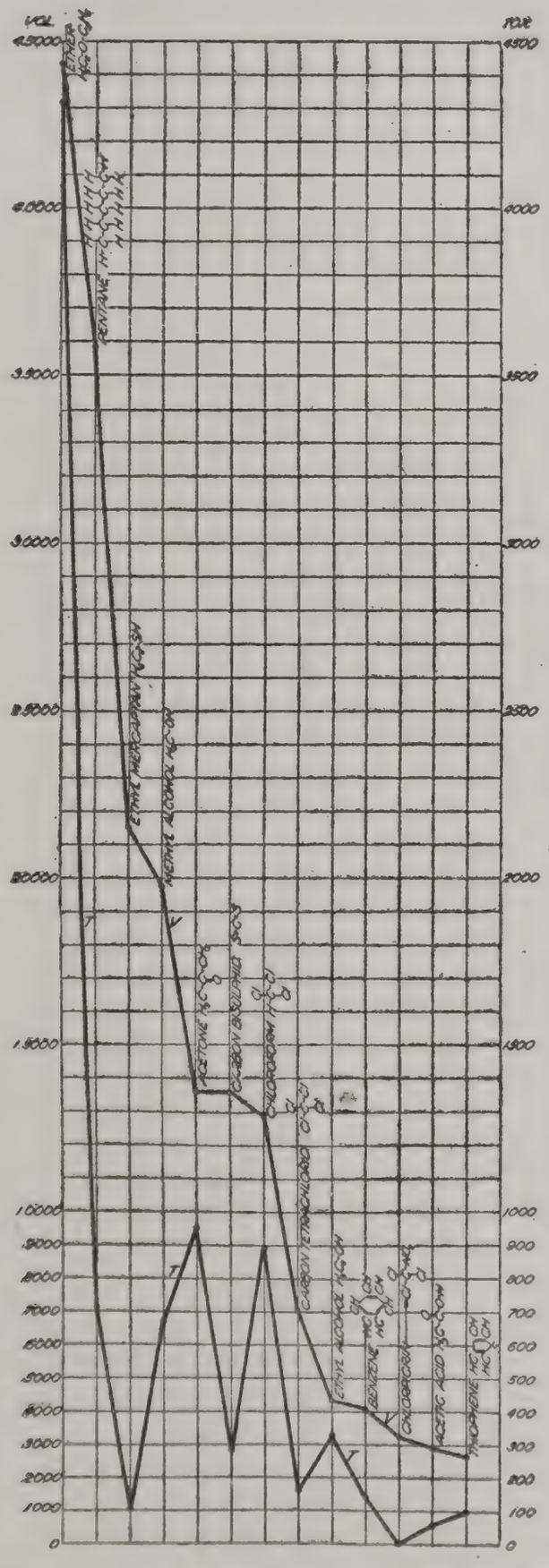

Fig. 1.—Volatility (V) in gram-molecules evaporating in 400 minutes and the toxicity (T) in millionths of a gram-molecule killing insects in 400 minutes.

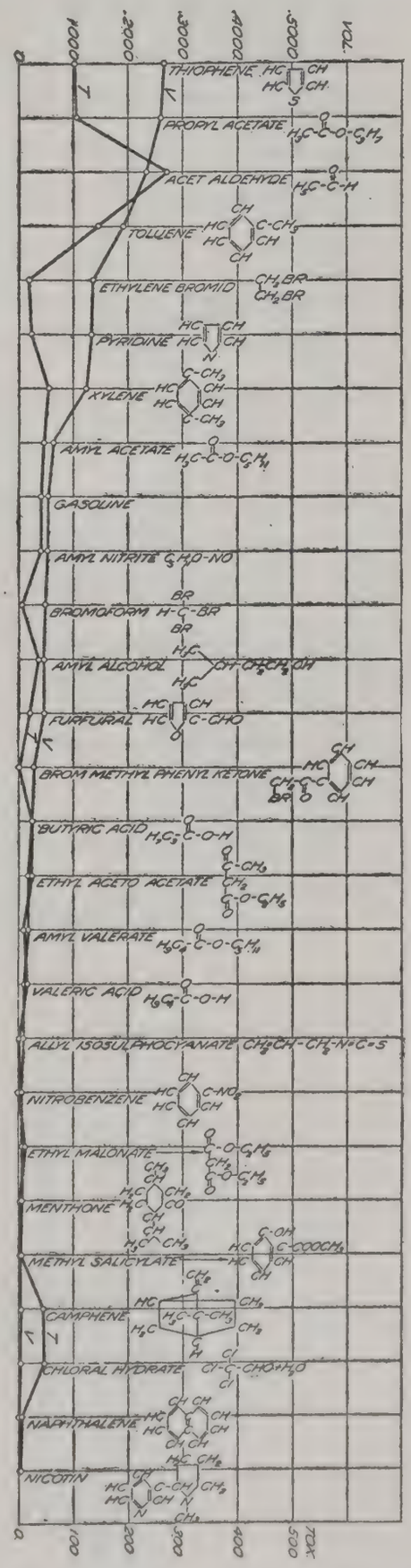

Fig. 2.—Continuation of figure 1, showing less volatile compounds.

hence, they are not included in the results. Pinene, terpinol geranyl acetate, and to some extent citral on exposure to the air, tend to form a

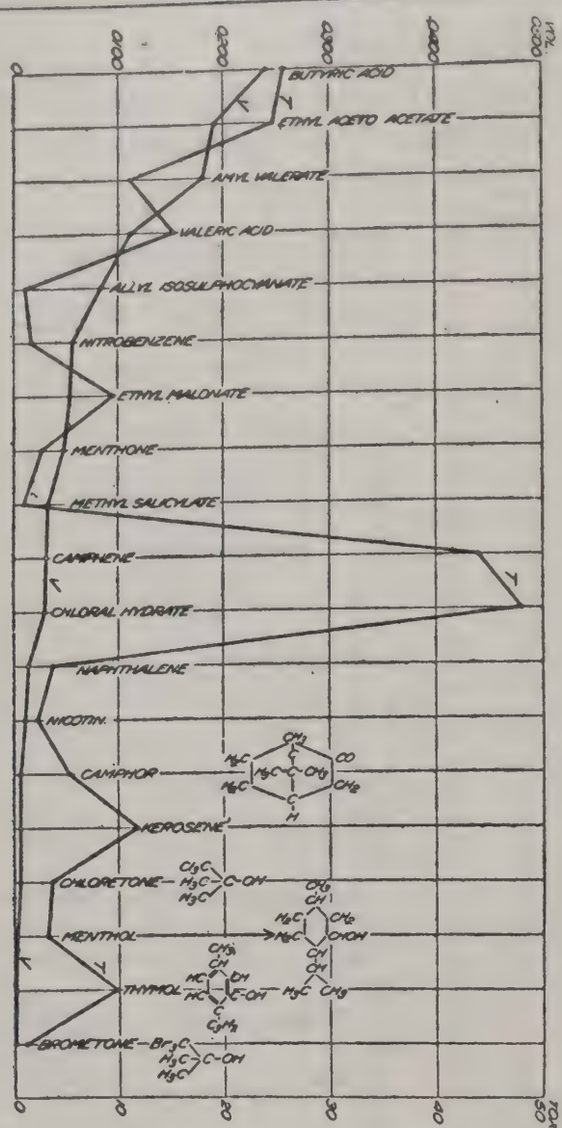

Fig. 3.—Volatility and toxicity of the slightly volatile compounds on a larger scale than in figure 2.

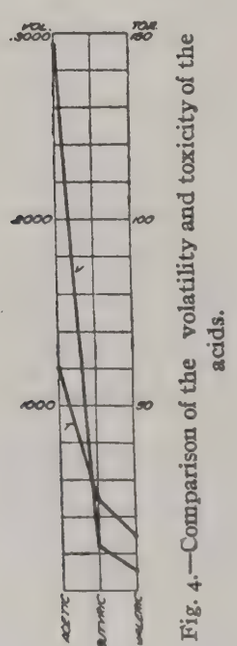

Fig. 4.—Comparison of the volatility and toxicity of the acids.

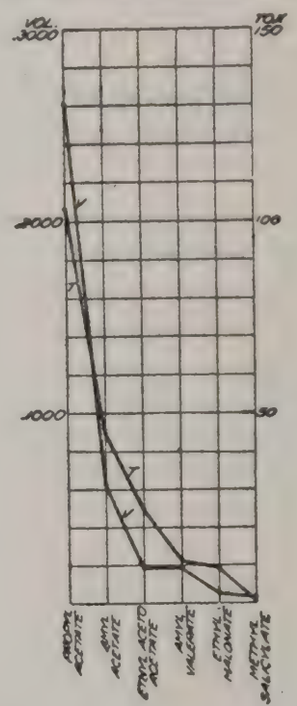

Fig. 5.—Comparison of the volatility and toxicity of the esters.

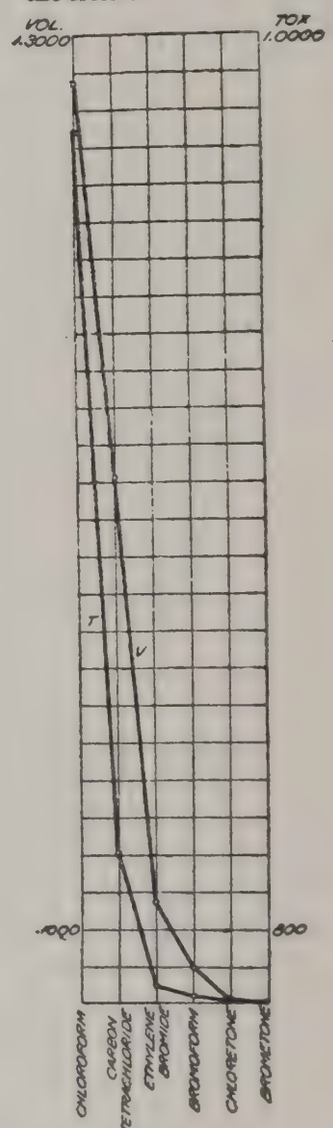

Fig. 6.—Comparison of the volatility and toxicity of the halogen derivatives.

gummy mass without completely evaporating. The toxicity of these compounds, particularly piene and terpinol, is variable. Pinene usually fails to kill the flies, while terpinol may kill with a certain dose one day, while the following day the same dose is not fatal. Usually unless the flies die in a short time after the introduction of the material, they will survive the fumigation. These erratic results are no doubt due to the oxidation of the terpene on exposure to the air, thus producing a substance which is not so toxic to the insect. Inasmuch as many of the essential oils contain terpenes producing such gummy residues on exposure to the air, it is at once apparent why varying results have been reported as to their value as insecticides.

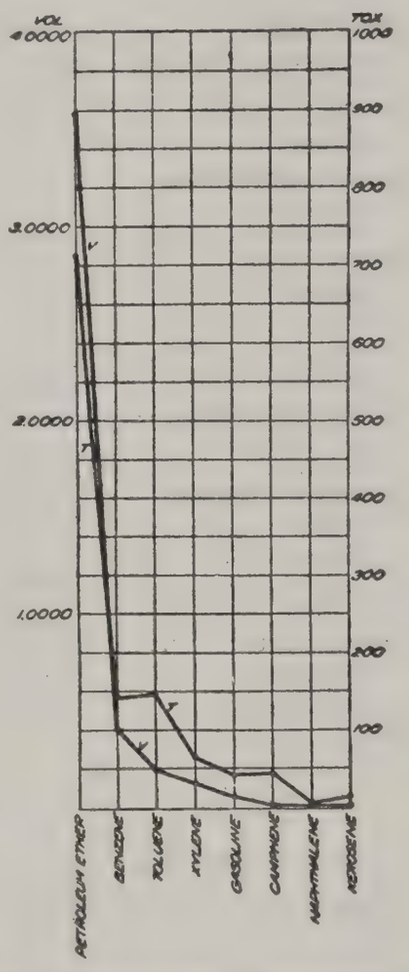

Fig. 7.—Comparison of volatility and toxicity of the hydrocarbons.

Table I and figures 1, 2, and 3 show that the toxicity of volatile organic compounds is closely correlated with their volatility. In general, the less volatile the chemical the more toxic it is even where the compounds are strikingly different in their chemical composition. When related compounds are considered, as in figures 4, 5, 6, and 7, this agreement is even more marked. Exceptions are noted, as in carbon bisulphid, ethyl mercaptan, and particularly chlorpicrin. These exceptions are not due to vapor density, nor primarily to water solubility, but are no doubt due to their chemical composition or to some peculiar action of the chemical. Hydrocyanic acid, although not included in this paper, would be an exception, owing to its extreme solubility in water and the fact that such minute quantities are sufficient to inhibit the action of oxidizing enzyms. Chlorpicrin may be likewise an enzym poison. The remarkable point of data here presented is not that there are a few exceptions, but the fact that there are so few exceptions among so large a number of very different chemicals which are strikingly different in their toxicological action on higher animals. It is interesting to note that ethyl alcohol is more toxic to insects than methyl alcohol, the reverse of that which takes place in higher animals

TABLE I.—*Relation of the volatility of organic compounds to their toxicity*

Name of compound.	Volatility in gram-molecules evaporating in 400 minutes.	Toxicity in millionths of a gram-molecule killing in 400 minutes.	Name of compound.	Volatility in gram-molecules evaporating in 400 minutes.	Toxicity in millionths of a gram-molecule killing in 400 minutes.
Ethyl ether	4.4245	4318.4	Furfural	.0457	20.8
Petroleum ether	3.5841	713.3	Brommethylphenyl-ketone	.0282	2.4
Ethyl mercaptan	2.1541	109.9			
Methyl alcohol	1.9776	671.8	Butyric acid	.0241	25.8
Acetone	1.3631	954.3	Ethyl acetoacetate	.0192	24.8
Carbon bisulphid	1.3616	286.3	Amyl valerate	.0182	11.2
Chloroform	1.2870	894.6	Valeric acid	.0113	15.3
Carbon tetrachlorid	.7067	161.9	Allyl isosulphocyanate	.0085	1.2
Ethyl alcohol	.4342	331.2	Nitrobenzene	.0058	1.8
Benzene	.4097	142.3	Ethyl malonate	.0054	9.6
Chlorpicrin	.3243	1.7	Menthone	.0049	2.9
Acetic acid	.2936	60.0	Methyl salicylate	.0033	1.0
Thiophene	.2659	102.2	Camphene	.0032	44.0
Propyl acetate	.2610	103.4	Chloral hydrate	.0030	48.0
Acetaldehyde	.2343	273.2	Naphthalene	.0013	3.9
Toluene	.1918	147.5	Nicotin	.0010	2.4
Ethylene bromid	.1363	18.6	Camphor	.00068	5.2
Pyridine	.1347	21.7	Kerosene	.00067	11.9
Xylene	.1241	64.9	Chloretone	.0005	3.6
Amyl acetate	.0627	44.8	Menthol	.00019	3.2
Gasoline	.0520	42.0	Thymol	.00014	9.9
Amyl nitrite	.0512	41.1	Brometone	.00009	1.1
Bromoform	.0486	7.7			
Amyl alcohol	.0460	38.2			

DISCUSSION OF RESULTS

Holt,[1] working with the cockroach, states that the toxicity of a volatile organic compound increases as the boiling point increases, up to a certain point, beyond which an increase in boiling point is accompanied by a decrease in toxicity. In the writer's own work the results show an increase in toxicity up to where the compound is so slightly volatile (b. p. 225° to 250° C.) as to be of no value. Holt used a fixed quantity of each compound in uniform flasks, giving the time required as an index of toxicity. Under such conditions a larger quantity of a high boiling point compound than would volatilize was placed in the flask. Although such compounds required longer to kill the cockroaches in Holt's flasks, the amount of vapor which produced the death was much less than was considered to be the case. The apparent decrease in toxicity in his experiments was really an increase, since the dose was greatly diminished, although the period of time was increased. The question naturally arises as to why the volatility of a chemical should be related to its toxicity. The following seems to be a reasonable explanation. The vapor present in the air is taken into the tracheæ of the insects and is

[1] HOLT, J. J. H. THE COCKROACH; ITS DESTRUCTION AND DISPERSAL. *In* Lancet, v. 190, no. 4840, p. 1136–1137. 1916.

condensed upon reaching their finer divisions. If the compound is very volatile, it will evaporate and readily pass out of the insect, while if very slightly volatile it will remain in the insect, and will penetrate the tissues and produce the poisonous reactions which lead to the insect's death. In higher animals, when the compound is taken into the lungs, it is rapidly removed by the blood and carried to all parts of the body, giving it an opportunity to react chemically with the tissues. For this reason the toxicity of volatile organic compounds is more closely correlated with the chemical composition when introduced into the higher animals, while in insects toxicity is more closely associated with volatility than with chemical composition.

SUMMARY

In general, the toxicity of a volatile organic compound is correlated closely with its volatility.

A decreasing volatility is accompanied by an increased toxicity.

The boiling point of the chemical is a general index of its volatility.

Compounds with boiling points of 225° to 250° C. are usually so slightly volatile that they do not produce death except after very long exposures.

The structure of the respiratory system of the insect is probably responsible for the remarkable influence of volatility on the toxicity of the vapor of volatile organic compounds.

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THE CYCLAMEN MITE

By G. F. MOZNETTE,

Assistant Entomologist, Oregon Agricultural Experiment Station

INTRODUCTION

The cyclamen mite (*Tarsonemus pallidus* Banks) has for some time been known as a greenhouse pest. For an arthropod so commonly and widely known to the florists of this country, comparatively little concerning its life economy is recorded. Serious outbreaks have occurred at irregular intervals, and more or less damage is done nearly every year.

During the past season the cyclamen plants in a greenhouse at Corvallis, Oreg., appeared badly infested with some pest. Upon examination of the foliage, especially the young developing leaves from the corms, they were found to be infested with a mite which was determined as *Tarsonemus pallidus* Banks by Dr. Nathan Banks, of Cambridge, Mass. This mite is without question a very serious floral pest, being widely distributed over the United States. The writer having often made an examination of specimens from various parts of the country and of cyclamen stock in a number of floral concerns in the Northwest, decided that, as scarcely anything other than the original description has been published, it appeared appropriate to bring together at this time, as far as possible, the recorded facts concerning the pest.

HISTORY OF THE SPECIES

The adults were described by Banks in 1899(1)[1] from specimens sent him by Mr. F. A. Sirrine, of the Jamaica branch of the New York Agricultural Experiment Station. He reported it as occurring on chrysanthemums in a greenhouse.

[1] Reference is made by number to "Literature cited," p. 389–390.

In 1913 Britton (5) published a short note stating that, while inspecting nursery stock at a florist's in Bridgeport, Conn., the species was found on chrysanthemums which had dropped and on which the petals had withered and died. In a large flower, though freshly cut, dead and brown petals were found scattered through the blossom, which at once indicated that something was wrong, and investigations proved that the cyclamen mite was responsible for the damage.

In 1915 Britton and others (6) published a short account of some experiments in controlling *T. pallidus*, which had injured snapdragon plants in greenhouses in Connecticut, and recorded it as being found on cyclamen stock. Nothing concrening the life habits of this pest is mentioned and nothing concerning its control on cyclamen stock, apparently its principal host, is recorded.

Banks (4) records this species as being injurious to greenhouse plants in this country. In 1915 Weiss (12) records this species as occurring on chrysanthemums in New Jersey.

The writer's attention was first called to the cyclamen mite in the early fall of 1916 at Corvallis, Oreg. The superintendent of the experiment station greenhouses reported trouble to his cyclamen stock, and upon an examination they were found to be badly infested by this mite.

Specimens were received on December 18, 1916, from florists in Des Moines, Iowa, who have been more or less troubled with the cyclamen mite for the past few years. However, in 1916 they had found it more troublesome than ever before and lost a large number of plants by its ravages. Other specimens were received from Illinois growers who raise large quantities of plants annually, some as high as 100,000 plants during the year, and several recorded the fact that they had been especially afflicted with the cyclamen pest during the fall of 1916. In each instance specimens of infested plants were obtained by the writer from the different concerns, in order to be certain that the growers did not have the cyclamen mite confused with the greenhouse thrips. Numerous reports have been received also from Wisconsin, Pennsylvania, and Michigan. A large grower of cyclamen in Detroit sent specimens and wrote as follows:

> We have one large house of cyclamen which has been attacked and practically ruined by this pest.

A number of examinations were made of cyclamen stock in greenhouses in the Northwest (in Washington and Oregon). The mite was quite prevalent, and in several cases the growers lost their entire stock of cyclamen the past season (1916). The data on hand show that growers in 1916 have each lost from 200 to 2,000 plants owing to this mite, and no doubt this estimate is low. Cyclamen plants in bloom bring from 75 cents to $1 per plant during the holidays, and when we consider that it takes over a year to grow the plants, the loss to growers is considerable.

DISTRIBUTION OF THE MITE

From the foregoing it will be seen that this mite has quite a wide range, being found as far east as Connecticut and as far west as Washington and Oregon. It probably occurs throughout the United States wherever cyclamen stock is grown. The known distribution is shown on the map (fig. 1).

Dr. L. O. Howard kindly forwarded data on host plants and distribution and placed at the disposal of the writer slides from the Bureau of Entomology at Washington, D. C. Dr. W. E. Britton sent for examination and study slides which were collected at various greenhouses in Connecticut in 1914 and 1915. Prof. H. A. Gossard, of Ohio, Prof. G. Herrick and

FIG. 1.—Map of the United States, showing distribution of *Tarsonemus pallidus* Banks, the cyclamen mite. (Original.)

Prof. C. R. Crosby, of New York, and Dr. Philip Garman, of Maryland, have forwarded data on distribution and reported this mite as occurring in greenhouses in those States. Mr. William A. Ross, of Vineland Station, Ontario, Canada, has reported it as a serious pest to cyclamen in the Province of Ontario. Numerous growers throughout the United States have at various times forwarded specimens and suggestions.

CORRECT NAME OF THE SPECIES

From a careful consideration of data in the writer's possession he is led to believe that the species in question is properly named "*Tarsonemus pallidus* Banks." After examining what the writer thought to be cotypes of the Bureau of Entomology, Washington, D. C., the material collected from this locality and other parts of the country agree with the

slides from Washington. These slides bear the corresponding data which follow the original description. The original description, however, states that *T. pallidus* possesses two claws on the posterior leg of the male, where in reality the material obtained from the National Museum shows but one claw, and corresponds with the material in the writer's possession from various parts of the United States.

The matter has been taken up with specialists, and Dr. Banks has pronounced it his *T. pallidus* after comparing material. Later the matter was taken up with Dr. H. E. Ewing, who has very generously contributed to the placement of the species, and has come to the conclusion that apparently the species is *T. pallidus* Banks. *T. pallidus* closely resembles *T. approximatus* Banks and also *T. assimilis* Banks (3). The important characteristics from a systematic standpoint, so far as the male is concerned, are those of the posterior pair of legs (fig. 2, *C*).

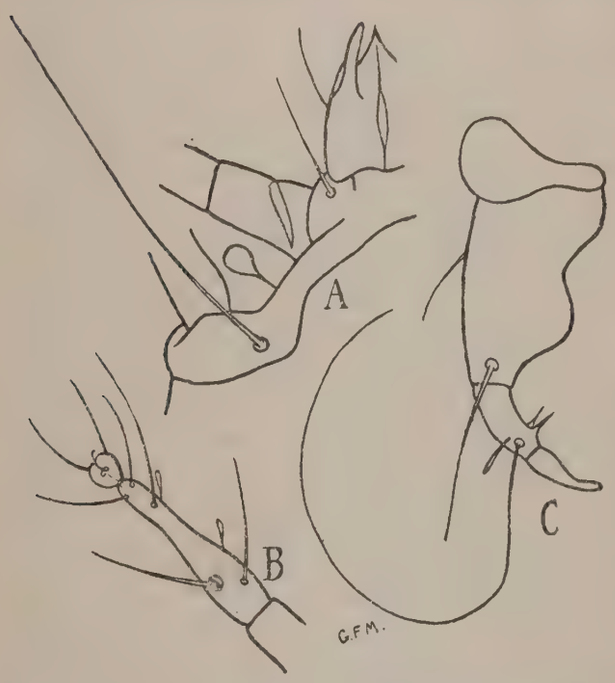

FIG. 2.—*Tarsonemus pallidus: A*, long tactile bristle and large clavate organ between the first and second legs: *B*, tarsus of foreleg of the female: *C*, posterior leg of male.

SYSTEMATIC RELATIONSHIP

The species of mite here figured is a member of the family of mites known as Tarsonemidae, a small family of much biological importance. According to Banks (4), they are soft-bodied mites, and in some ways resemble the Tyroglyphidae, but the females differ from them, as well a from all other Acarina, in having between legs I and II a prominent clavate organ of uncertain use. They are very small mites, and the males and females vary greatly in appearance, and might easily be taken for entirely different species.

The family contains two subfamilies, Pediculoidinae and Tarsoneminae. The subfamily Tarsoneminae includes but two genera, the species differing from those of the other subfamily in that the hind legs of the female end in long hairs and the hind legs of the male are about as long as the third pair. The two genera Scutacarus and Tarsonemus are represented by a considerable number of species. Many of the species of Tarsonemus are of distinct economic importance. The genus Chironemus was erected by Canestrini and Fanzago (7) for some soft-bodied mites found in colonies on leaves after the manner of Tetranychus. The name being preoccupied, the authors changed it the following year to Tarsonemus.

NOTES ON SOME OTHER ECONOMIC FORMS

In the past it has been suspected that mites of the genus Tarsonemus are a frequent cause in promoting diseases in plants. It seems likely that many of the diseases to which hothouse plants are subject are due to these mites. The species are so small and so difficult to investigate that very little attention has been paid to them. There are probably many species, but very few have been described, and about these little is known.

T. floricolus Canestrini and Fanzago (7) has been found on the leaves of a large variety of plants; *T. spirifex* Marchal (8) has been reported on diseased oat plants; *T. chironiae* Warburton (11) is mentioned as attacking ferns in England; *T. tepidariorum* Warburton (11) as attacking a greenhouse plant, *Chironia exigera*, in England; *T. ananas* Tryon (10) is reported as a forerunner of a disease of pineapples known as "fruitlet corerot" in Queensland; *T. culmicolus* Reuter (9) causes diseases of grasses in Finland, Russia; and *T. waitei* Banks (12) is reported to be of economic importance through its destruction of terminal peach buds.

SPREAD OF THE SPECIES

The spread of the cyclamen mite is no doubt effected by the shipment of seedlings and specimen plants from one place to another. Plants are shipped by growers either as seedlings packed 5 or 10 in a package, with the roots surrounded by moist sphagnum moss, or as specimen or blooming plants shipped in paper pots packed in crates. Plants so packed will travel 7 to 10 days without injury. It often happens that a florist's stock of plants are killed for some reason by fungus or other trouble, or that he is tardy in sowing his seed soon enough to secure plants for the holiday trade, and he is therefore forced to purchase seedlings or mature plants from some extensive grower. If a wholesale florist is troubled with this mite, he can readily transmit the pest to other localities, either on the plants or in the soil in which they are set, when shipping plants to other florists. Sometimes the plants are not badly infested on leaving the wholesale grower, and no signs of injury are noticed; but a short time after they reach their destination they may become seriously infested, as under favorable conditions the mites multiply very rapidly.

HOST PLANTS

T. pallidus does not occur on a great variety of host plants, having apparently thus far confined itself to a few species only. From data on hand it would seem that the mites have a preference for cyclamen, especially the young tender growth of the plants. Next to cyclamen, the mite no doubt prefers the chrysanthemum, and it has also been reported on the snapdragon (*Antirrhinum* spp.) in Connecticut and Maryland. Where old cyclamen corms are preserved in the greenhouse, one may find specimens about the corms throughout most of the year.

CHARACTER OF THE INJURY

The work of the mites resembles a gall on the older leaves as well as on the young, developing leaves. They do not generally attack the older leaves, but work mostly on the young leaves just unfolding (Pl. 52, *D*). The injury noticed on the older leaves is usually done while the leaves are small (Pl. 52, *C*, *D*).

The mites apparently habitually shun the light and consequently penetrate to the innermost recesses accessible, in accord with the antipathy that this act evinces, especially when suddenly exposed. On the plant they commonly resort to the depressions. The color of the mites is such as to render their detection a matter of more than ordinary difficulty.

With their styliform mandibles they probe the tissues, in order, apparently, to imbibe the juices found there. This action on their part results ordinarily in the appearance of minute brown specks, a sort of russeting. Such marks are often discernible on the inner walls of the curled leaves. The mites suck up the liquid contents of the tissues, leaving the injured parts shriveled. Owing to this injury (Pl. 52, *A*, *B*) and the continued growth about the damaged parts, the leaves are so distorted (Pl. 51, *A*) as to give the plant a very dwarfed and shriveled appearance. Often the leaves become very much thickened at the points immediately surrounding the injured parts.

The writer found that the buds, both leaf and flower, are ordinarily badly infested. The most noticeable effect from the attacks of this mite is the distortion of the leaves (Pl. 52, *A*), which stunts the plants, and the discloration of the flowers (Pl. 52, *A*, *B*). Flowers which should have been a soft pink or red come blotched and streaked, and ultimately the blooms wilt and die prematurely. This injury to the flower parts is, of course, mainly noticeable when the flowers are in bloom. Most of the injury is accomplished, however, in the flower-bud stage (Pl. 52, *C*). The mite in all stages of development occurs between the calyx and corolla, within the corolla and on the stamens and ovary. When the infestation on plants is severe, as was the case in most greenhouses visited the past season, the plants appear ultimately so badly curled and distorted as to be unsalable, and they do not bloom normally (Pl. 51, *A*).

DESCRIPTION OF TARSONEMUS PALLIDUS

THE EGG

The egg (Pl. 52, *E*), while very small, is large, considering the size of the adult. It is elliptical and white in color and possesses a pearly appearance, resembling a minute slug egg. It measures from 128 to 130 μ in length and 65 to 71 μ in diameter. The surface of the chorion is apparently without any markings whatever, no constrictions occurring.

It does not change in color in development as some mite eggs do, and the resultant larva is pure white in color. The egg has a rather delicate shell, and numerous shells may be found collapsed among the masses of unhatched eggs and mites.

THE LARVÆ

The female larva (fig. 3) is of a pale-white color, becoming, as it matures, a light yellowish white. The female has only three pairs of legs. When the larva has just emerged from the egg and has stretched itself out, it is a little less than 0.2 mm. in length. Soft, wrinkled, elastic skin occurs on the dorsal side, between the head and the first two dorsal shields and also between the two front and three posterior dorsal shields. The head is rounded off and carries two short lateral bristles. The first dorsal shield is nearly three-cornered, and is provided with two pairs of bristles, the longer pair serving as touch bristles. The second dorsal shield is square, and shows on each side a short bristle which stands out horizontally. The third dorsal shield is nearly round and has in the center a pair of fairly long bristles. This third dorsal shield is grown together with the fourth, which carries a row of four short bristles arranged horizontally. The last, or fifth, dorsal shield is provided with four long bristles and covers the end of the abdomen so that it is also visible on the ventral side.

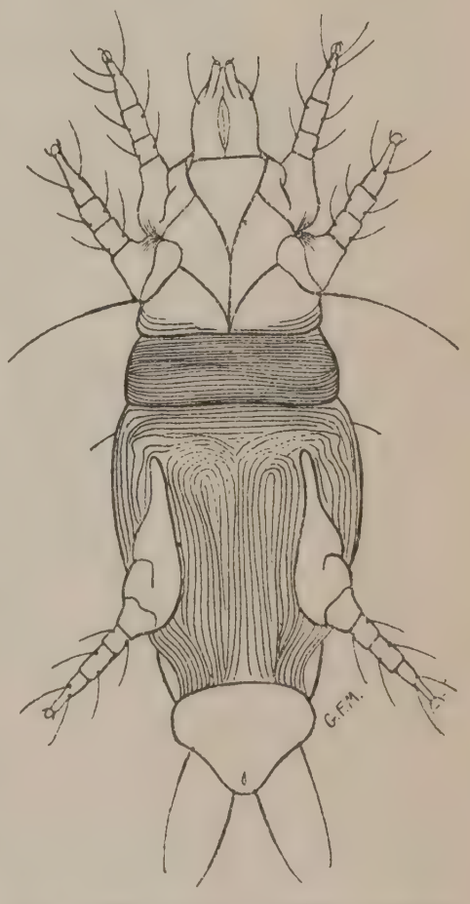

FIG. 3.—*Tarsonemus pallidus:* Ventral view of female larva. Much enlarged. (Original.)

The ventral surface (fig. 3) shows the head, the neck, and the four epimera which have grown together into a shield. A very large part of the ventral side is soft, wrinkled, and elastic. Both of the epimera of the third pair of legs are three times as long as wide and longer than the other free leg parts together. The point of the abdomen is, as has already been noted above, covered by a thimble-shaped shield, which is carried at the very tip and alongside the four long bristles.

All six of the legs are very short; each is composed of five free parts. The sole of the first pair of legs consists of a suction cup and one small claw, which appears cleft; the soles of the last three pairs of legs consist of a suction cup and two small claws. The claws are used on rough surfaces, while the suction cups serve as excellent adhering organs on smooth surfaces. Such a sole with its claw is shown enlarged in figure

2, *B*. The measurements of the larvæ average 214 μ in length and 85 μ in width.

The male larva is practically the same in form, except it is a little smaller, and one can hardly detect it as being a male until one sees the developments occurring in the quiescent stage. It is, however, a little more stocky; the back shields compare favorably; the posterior epimera are a little more enlarged; and there is not so much elastic skin present.

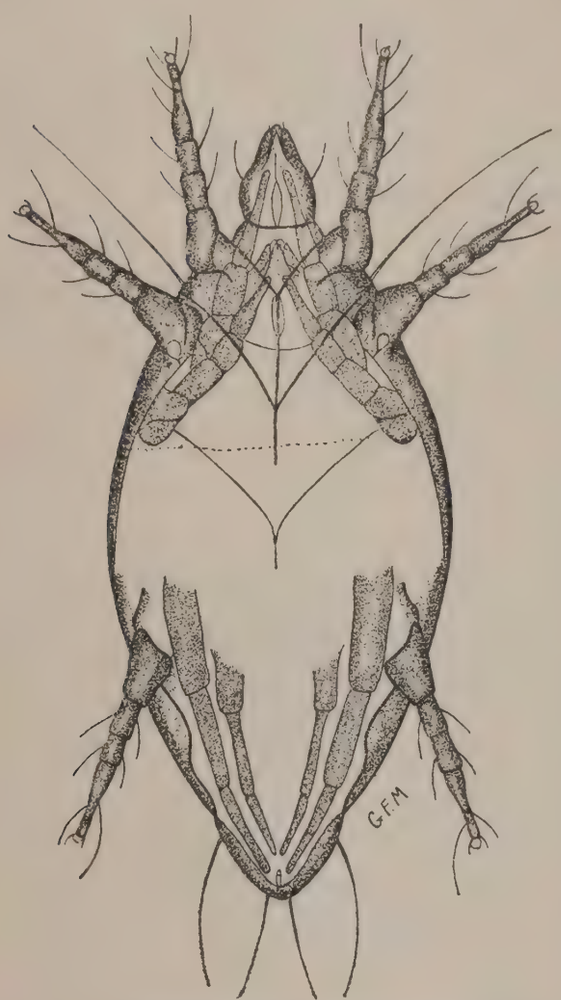

FIG. 4.—*Tarsonemus pallidus:* Female quiescent larval stage with development. Much enlarged. (Original.)

QUIESCENT STAGE

No nymphal stage was found in this species and instead of a nymph originating from a larva, as is the case in the life history of most mites, the larva transforms to a quiescent stage (fig. 4), which later gives rise to the adult form. The quiescent stage consists of the engorged larva, which in this stage is perfectly motionless and clumsy-looking. It is white in color, the same as the larva, and is somewhat hyalin. The writer has examined a large number of the quiescent forms alive and mounted in glycerin, and when so mounted the developing changes are plainly seen under the microscope. The addition of a fourth pair of legs and the clavate organs which the adult will possess is shown within the membrane. The quiescent period is no doubt a period devoted to the formation of new parts, and to various physiological processes preparatory to molting. In molting, the body moves back and forth within the old skin until it splits transversely along the cephalothoracic abdominal groove; then the cephalic end of the mite is slowly protruded from the old skin. In this form the wrinkled and elastic condition is not present, as with the engorgement of the immature larva the plates or folds in the larva are forced out. Measurements on a number of female quiescent forms give an average length of 242 μ and a width of 128 μ.

THE ADULT FEMALE

The adult female (fig. 5) has a large and broad body; the venter has one transverse line near the separation of cephalothorax and abdomen. The general appearance is almost hyalin, and the integument is somewhat

chitinized and of a brownish color. The capitulum is quite prominent, extending to nearly the middle of the first segment in the forelegs. It possesses a pair of hook-shaped upper jaws which together form a pair of pincers. Two short bristles are placed laterally.

The cephalothorax is as broad as long. The epimera of the first pair of legs are united to a median piece, or the epimera meet at an angle at the middle line and then form a narrow longitudinal keel that extends to the end of the cephalothorax. The epimera of the second pair of legs are united similarly as those of the first epimera. The ends of this median longitudinal sternum, or keel, curve outward to the sides of the body and form the boundary of the cephalothorax. The cephalothorax possesses two long touch bristles (fig. 2, *A*) which arise dorsally about the point between the first and second pair of legs. In front of the long touch bristles the female possesses, between the first and second pair of legs and under the back shield, a pair of club-shaped hairs or organs which are planted in small shallow cups. The object of these organs is unknown. Perhaps they are balancing organs or auditory organs, or possibly both at the same time.

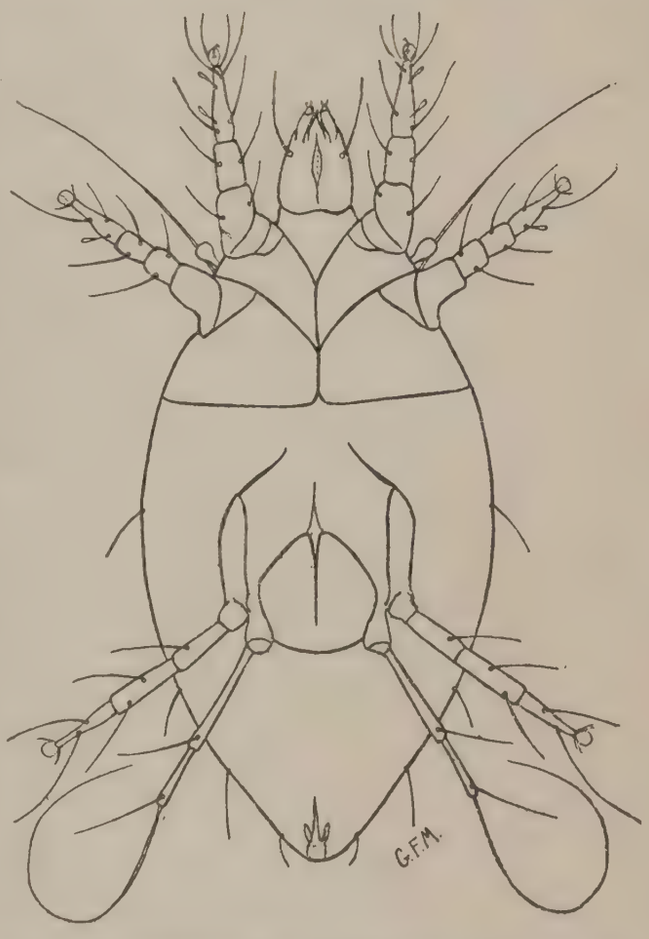

FIG. 5.—*Tarsonemus pallidus:* Adult female. Much enlarged. (Original.)

The abdomen is longer and broader than the cephalothorax, and has three short bristles on each side and a pair near tip of body. The legs of the anterior group are subequal. The legs are short but rather slender, with few hairs. Tarsus I has a subbasal clavate hair, with a long hair near by, a pair near the tip above, and a clavate hair just before them. The third pair of legs are more slender than the forelegs; the segments have grown together, the third segment being real long. On the fourth pair of legs only three parts were distinguished, the parts being grown together more or less. It is noteworthy that on the sole of the leg I only one claw (fig. 2, *B*) is seen, and on leg II and III two small claws, while leg IV terminates in two appendages, one of which is acicular, the other twice the length of this, a long curved hair that gradually becomes exceedingly fine.

The whole dorsal surface of the female shows the head and a number of shields which possess hairs. The shields are so grown together that they are hardly visible in glycerin and overlap each other. On the ventral side one does not see any trace of a skin; it has totally hardened. The female measures 240 to 260 μ in length and 130 to 140 μ in width.

THE ADULT MALE

The general appearance of the adult male (fig. 6) is more hyalin, and the body is more angular oval than that of the female. The capitulum is moderately large, tending downward, rounded in front, with one pair of quite long frontal bristles. The capitulum and sexual organs, that terminate the body in front and behind, respectively, are almost identical in form and size, being ovate and sightly excavated at the base and terminally rounded.

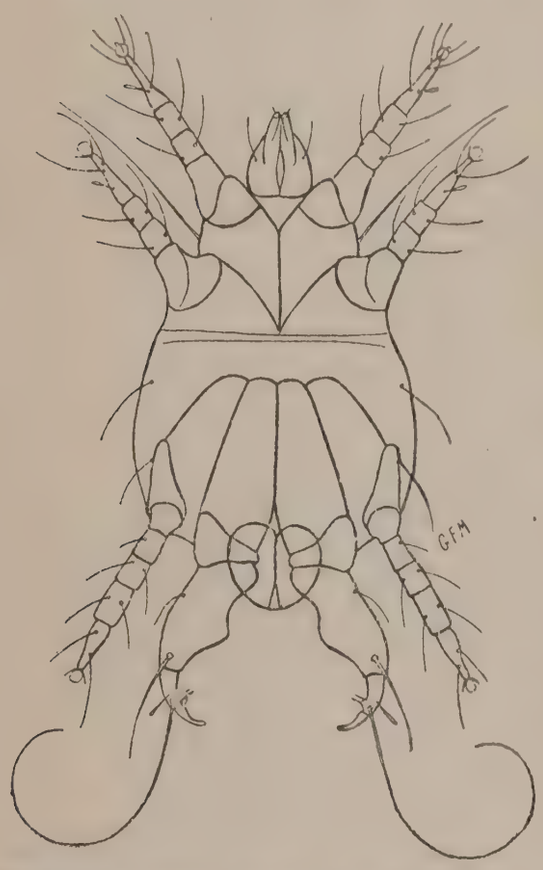

FIG. 6.—*Tarsonemus pallidus:* Adult male. Much enlarged. (Original.)

The cephalothorax is as broad as long. The epimera of the first pair of legs are united at the median line, the same being true of the epimera of the second pair. The median line touches the two transverse lines, which no doubt terminate the cephalothorax. The dorsal part of the cephalothorax is provided with two pairs of bristles, one pair, exceedingly long, called the "tactile bristles."

The abdomen is larger and broader than the cephalothorax. The anterior group of legs are subequal and sparsely clothed with moderately long bristles. The first pair terminates in a single claw, while the second and third pair are two-clawed. The anterior group of legs are provided with a clavate hair on the first segment. The third pair of legs are similar but slightly longer than the second pair, and are devoid of the clavate hair. The fourth pair of legs is very stout, twice the thickness of the third pair. The first joint is broader than long; the second is rather more than twice as long as broad, and is furnished on the inner face with a broad curved expansion and with a stout terminally inclined tactile bristle and a lateral hair near the middle. The next joint possesses inwardly two divergent spines which are short; laterally and terminally inclined is a long touch bristle which grows finer toward the end. It also possesses a short clavate hair which stands rather upward and is

easily removed. The leg terminates in a single stout slightly curved gradually pointed claw. The epimera of the third pair conjoint those of the fourth pair internally, and the four together are considerably and equally advanced in front. The male measures 180 to 185 μ in length and 95 to 100 μ in width.

LIFE HISTORY OF THE CYCLAMEN MITE

OVIPOSITION

A single egg is deposited at one time, the egg being so large as to take up at least one-half of the female's body. The eggs are laid in masses in moist, dark places provided by the curling and distortion of the leaves of the cyclamen plant. This may occur by the curling over of the edge, or the basal lobes of the leaves may curl. The eggs are placed here and there in the folds so provided and have no set position. They were never found exposed on the plant, as they are very sensitive to the sun's rays and soon shrivel. Moisture is always present where they are found. When the egg hatches the shell collapses completely.

The length of the egg stage no doubt will vary and depends mainly upon the temperature. From the 10 eggs observed the average proved to be about 11 days. The laboratory where the experiments were carried on had a daily temperature of about 70°, corresponding quite favorably with the greenhouses where the cyclamen plants were kept. Egg deposition goes on over a long period of time, eggs being found from the early part of November until the last of March, and no doubt the eggs may be found over a longer period, indicating that a large number of generations may be produced. (See Table I.)

TABLE I.—*The length of the egg stadium of the cyclamen mite*

No.	Date of oviposition.	Date of hatching.	Length of egg stage.
	1916.	1916.	*Days.*
1	Dec. 13	Dec. 23	10
2	...do.....	...do.....	10
3	...do.....	...do.....	10
4	...do.....	...do.....	10
5	...do.....	Dec. 22	9
6	Dec. 14	Dec. 27	13
7	...do.....	Dec. 26	12
8	...do.....	Dec. 27	13
9	Dec. 15	...do.....	12
10	...do.....	Dec. 26	11

LARVAL HABITS

When ready to hatch, the larva ruptures the eggshell at the cephalic extremity and being curled up within the egg soon commences to stretch itself out. Upon hatching nothing but the chorion is left; remains of the

hatched eggs are noticed in numbers scattered here and there over the curled inside portions of the leaves. The young larva does not feed immediately, but after an hour or so becomes active and crawls here and there about the leaf in the neighborhood of the eggs. As the larva feeds, the elastic or wrinkled skin slowly expands or is stretched out. Molting only when transforming to the adult, it is provided with many of these plaits for subsequent expansion. The expansion occurs in the abdominal region principally and to a lesser extent in the posterior part of the cephalothorax. After all the leaflike wrinkled skin is expanded and the larva becomes sufficiently engorged, it assumes the quiescent stage. The larva is very active and may be seen traveling here and there about the masses of eggs and eggshells. It is surprising how much the larva is capable of expanding without molting its skin.

The larval period, like the egg stage, varies considerably in length, depending on various circumstances, but the average of 10 larvæ taken for the active stage is about seven days—that is, from the time the larva emerges until it enters the quiescent stage. The larvæ may be found from November until the last of March. The active stage of the larva is considerably longer than that of the quiescent stage. (See Table II.)

TABLE II.—*Life-history notes on the larval stadium of the cyclamen mite*

Date.	Larva.				
	1	2	3	4	5
1916.					
Dec. 22					Emerged.
23	Emerged	Emerged	Emerged	Emerged	
24					
25					
26					
27					
28					
29	Quiescent	Quiescent			
30			Quiescent		
31		Molted			
1917.					
Jan. 1	Molted				Quiescent.
2			Molted	Quiescent	
3					
4					
5					Molted.
6				Molted	
7					

TABLE II.—*Life-history notes on the larval stadium of the cyclamen mite*—Continued

Date.	Larva.				
	6	7	8	9	10
1916.					
Dec. 22					
23					
24					
25					
26		Emerged			Emerged.
27	Emerged		Emerged	Emerged	
28					
29					
30					
31					
1917.					
Jan. 1					
2	Quiescent	Quiescent		Quiescent	
3			Quiescent		Quiescent.
4					
5	Molted				
6		Molted	Molted	Molted	
7					Molted.

QUIESCENT STAGE

Among the numerous eggs, eggshells, and larvæ as the generations proceed, one may find numerous resting, or quiescent, forms. When the larvæ become sufficiently engorged, they become motionless. In the generations where the adults are present the writer has observed males carrying along behind them, clasped by the grasping posterior legs and supported on the apex of the abdomen, the 6-legged, whitish, smooth, immobile body of one of these quiescent forms whose long axis is placed at right angles to its own. Warburton (11) observed this same phenomenon for a similar species studied in England. Occasionally one may observe a male attack another male carrying such a burden and obviously try to wrest it from it. No experiments were carried on at this point to see whether actual fertilization took place before the female reached maturity, as is the case with some mites in other groups. The carrying and dragging of the inert females by the males were observed frequently.

In the quiescent stage, development is going on, and the resultant will be either a male or a female. On January 30, 1917, the writer found many quiescent forms on the cyclamen plants. In no case did the writer find a quiescent form with eight legs; it always possessed six. The quiescent stage always gave rise to one of the 8-legged forms, the females predominating.

The writer has mounted a large series of individuals of the quiescent stage to study internal changes. The development of a fourth pair of legs in each case examined showed whether it was to be a male or female.

In the female quiescent stage the clavate organs between the first and second pair of legs were plainly seen.

After a few days, during which there are the various internal changes, the molting process begins. The body moves in a series of twists and turns, when suddenly the old skin splits traversely along the cephalothoracic abdominal groove, and finally the adult mite emerges.

The length of the quiescent, or resting, stage varies somewhat, but the average of 10 specimens taken from the active larvæ through to molting was 3½ days. This would give the average for the entire length of the larval stage approximately 10 to 11 days.

HABITS OF THE ADULTS

The adults may be found at any time on the plants from November until late spring and no doubt may be found in the greenhouse all the year round. The males are comparatively short-lived, the females living longer. During the middle of January, 1917, more males were to be found than at any other time. The females seem more abundant during the fall and winter, when most of the damage to the plants occurs. It is almost impossible to get a clue to the number of generations by making observations in the greenhouse, since they overlap so completely. After the first generation, if the mites are at all abundant, eggs, larvæ, and adults no doubt may be found in the greenhouse simultaneously throughout the remainder of the year. During a portion of the year it is thought the mites become less numerous until there is no evidence of their presence when their food plants are not present; possibly the females semihibernate.

From the data at hand it is apparently true that the mites appear in early June in the greenhouse on the young plants from seed of the previous August, and produce generation after generation on the plants until the last of March, and no doubt longer the succeeding year. The mites then gradually become less abundant, again to appear later in the summer, being held over apparently by the semihibernating females in the soil scattered in the greenhouse.

This has been demonstrated somewhat on plants in the laboratory. The foliage was cut from the corms completely and allowed to dry out a little so that no growth was to be seen on the corms. These plants were left in this condition for several months and then watered thoroughly, and the foliage was allowed to grow. On previous observation only females could be found about the corms and in the soil before the foliage started. In a very short while the foliage was seen to be curling, and numerous adult mites were present.

REARING METHODS

Several sorts of rearing cages were tried in the work, but it was found that the use of but one gave the best results. The potted cyclamen plants were kept at first next to the window in the laboratory where

the light was bright, using the young tender foliage, the older leaves being stripped from the corms. The petiole of each leaf was surrounded with vaseline to confine the mites to the leaves. The mites are negative-phototactic, always endeavoring to get away from the light. They curled the tender young leaves in striving to seek crevices, and some even dropped to the soil and, hence, would not propagate successfully in the lighted places. Where crevices were cut in the leaf, only the covered eggs embedded in the crevice hatched, the uppermost eggs shriveling and dying. The eggs being so embedded in the crevice or in the curled leaves made it impossible to get data desired on the various stages. It was therefore thought that, since the mites were negative-phototactic, it would help if the individual plants were covered with battery jars surrounded with black paper. This proved quite satisfactory to establish the mites on the leaves, which were of medium size, and to study the habits of the species as the eggs in many cases were deposited on the surface exposed under the dark jar, and the incubation and habits of the succeeding stages could be studied. This also confined the moisture, but the darkening of the plant might, in cases where the plant is not sufficiently vigorous to withstand the period necessary to run a generation through, so diminish the chlorophyll in time as to cause the plant to die. It is necessary, therefore, that the plant be uncovered at intervals to prevent such an occurrence.

REMEDIAL CONSIDERATIONS

As most of the species of mites no doubt have an extremely primitive respiratory system, it is often difficult to control them satisfactorily by fumigation with various gases; hence sprays must be resorted to as a control measure. After the older cyclamen plants become badly infested there is not much hope of saving them, as the mites are usually concealed under the calyx and even to the inner flower parts of the buds so that it is quite impossible to reach them. When the older plants, particularly cyclamen, have become badly infested it usually will be advisable to burn them and sterilize the soil, but the grower should avoid getting his plants in this condition by exercising preventive measures when the plants are young.

Dusting the plants with sulphur dust or tobacco dust when the plants are heavily infested is of very little avail. Dipping the plants in an oil emulsion called Yel-ros, which contains a good deal of xylol, a very penetrating oil, helped some, and no doubt will free the later blooming plants for Easter. This was demonstrated on some of the infested plants in the Experiment Station greenhouses. This oil emulsion was tried out in the greenhouse at the rate of 1 to 40, with the result that very little burning resulted, and no doubt it may be used weaker. A number of plants which were retained came out in good shape. The Yel-ros is too severe a spray for the young plants, however, as a considerable amount of burning resulted.

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As heat is very penetrating, it occurred to the writer that possibly it could be used against this mite, but it was found that the plants could not be subjected to sufficient heat to kill the mites.

Finally, the volatile liquid-nicotine extracts and the nonvolatile or staple extracts, as "Black Leaf 40," may be used on cyclamen against this pest. "Black Leaf 40" has been used in Connecticut with safety on snapdragon plants, with the result that the new growth came out clean and uninfested. Fir-tree oil was also used with some success on snapdragons. However, no experiments were carried on with the use of "Black Leaf 40" or the volatile nicotine extracts against the mites on cyclamen plants. In the experiments carried on in several of the greenhouses in the vicinity of Corvallis, Oreg., neither the volatile extracts nor the nonvolatile nicotine extracts, such as "Black Leaf 40," with the addition of a small quantity of soap injured the young plants or the older plants when used at the rate of 1 to 1,000, or a teaspoonful to a gallon of water.

The staple nicotine extracts and the volatile nicotine extracts are practically identical, so far as killing properties are concerned. The nonvolatile extracts are, however, much cheaper, and wherever it is safe to use this form should be employed with the addition of a small quantity of soap. The soap assists in preventing the formation of small drops, which tend to roll off without penetrating to and thoroughly wetting the mites, causing the spray to cover surfaces more in the form of a thin film, also giving better penetration and sticking properties.

The volatile nicotine extracts, however, are preferred by most florists, in that they may be used for fumigating purposes and are preferred for those strains and varieties which might be injured by the use of the staple nicotine extracts which contain sulphate. "Black Leaf 40" has been used on chrysanthemums, snapdragons, and cyclamen plants with safety at the rate of 1 to 1,000, with the addition of a small quantity of soap, either 3 or 4 pounds to 100 gallons of the solution.

The florist should not wait until his plants are fairly grown before making an application of spray, but should start when the plants are quite young. Cyclamen seeds are usually sown in flats in rows 1½ inches apart about the middle of August, with other sowings made until January, depending on when the flowering plants are desired. In about 8 or 10 weeks after they are sown, the plants will be ready to be transplanted into other flats or into 2½-inch pots, as the case may be. They will not be more than 1 inch to 1½ inches high (Pl. 51, *B*); this is the time when the first spraying should be made. From then on the plants should be sprayed with the "Black Leaf 40" or some of the volatile extracts at the rate of a teaspoonful to a gallon of water, with the addition of a small quantity of soap, every 10 days until the flower buds are well developed and begin to show color. Do not spray after this, as the solution has a tendency to discolor the flowers, and the plants are then far enough along that the mite can do no damage.

In transplanting into the flats do not crowd the plants too much, as it is difficult to get the spray on the developing young leaves, and it is the young growth that should be protected. A good spraying apparatus for this purpose is a compressed-air hand outfit which will give sufficient force.

Some growers have recommended the use of pyrethrum by blowing the powder into the base of the plants with a small blower. The man using the powder should cover his mouth and nostrils with a piece of damp sponge to prevent any unpleasant consequences. The writer has not tried this method out, and can not speak for or against the method.

The mites usually attack cyclamen first during the dry weather. Poor cultivation, insufficient ventilation, and moisture encourage mite attack. Cyclamen particularly need a great deal of attention and care for their proper development. Nevertheless, the mites will attack vigorous plants, and a preventive measure should be employed.

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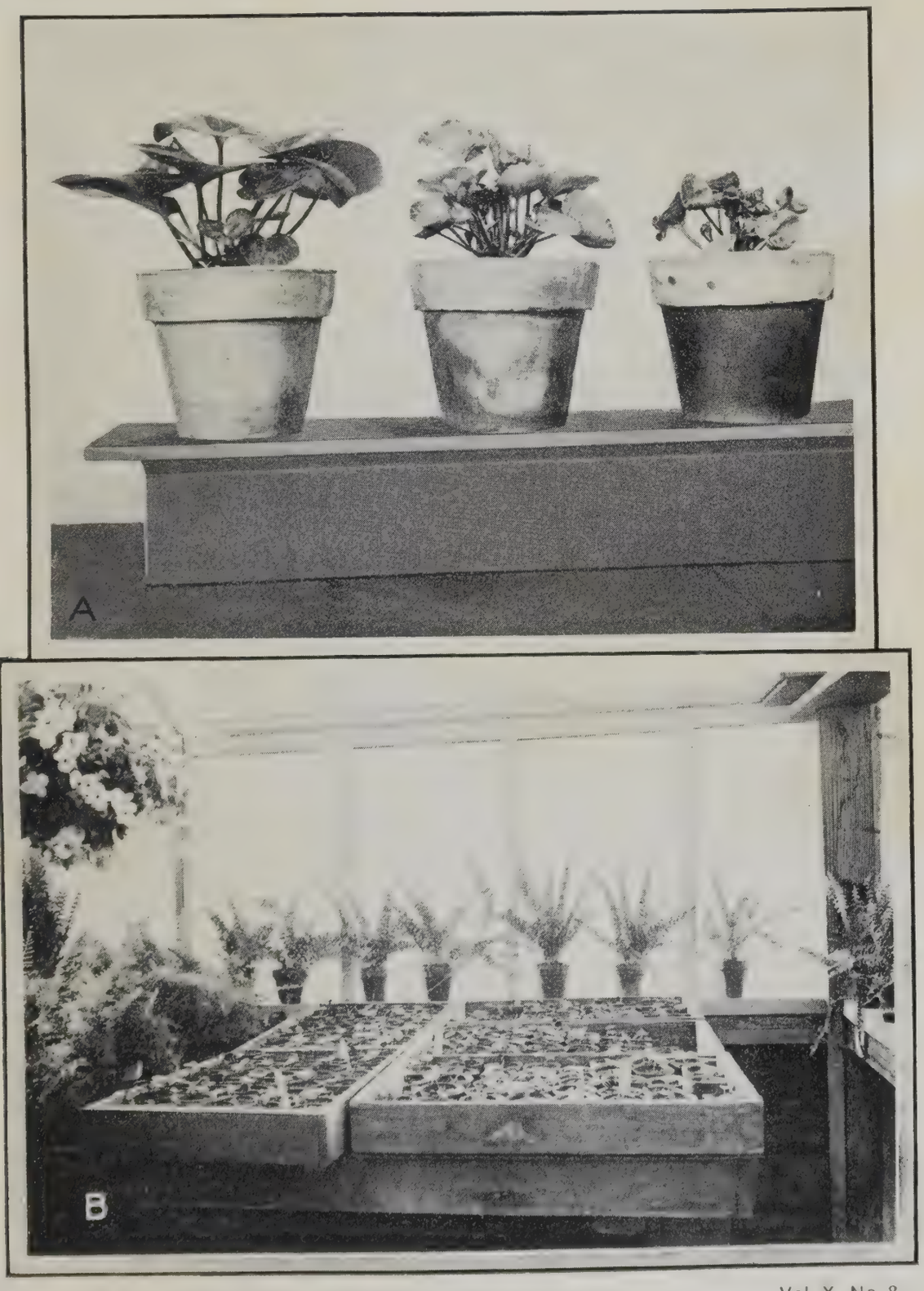
PLATE 51

A.—(Left to right.) A healthy, a somewhat infested, and a badly infested cyclamen plant with the characteristic distortion, dwarfing, and curling of the foliage.

B.—Flats in a greenhouse containing young cyclamen plants just transferred from seeds flats into small pots, showing the proper size at the time of the first spraying.


A
B

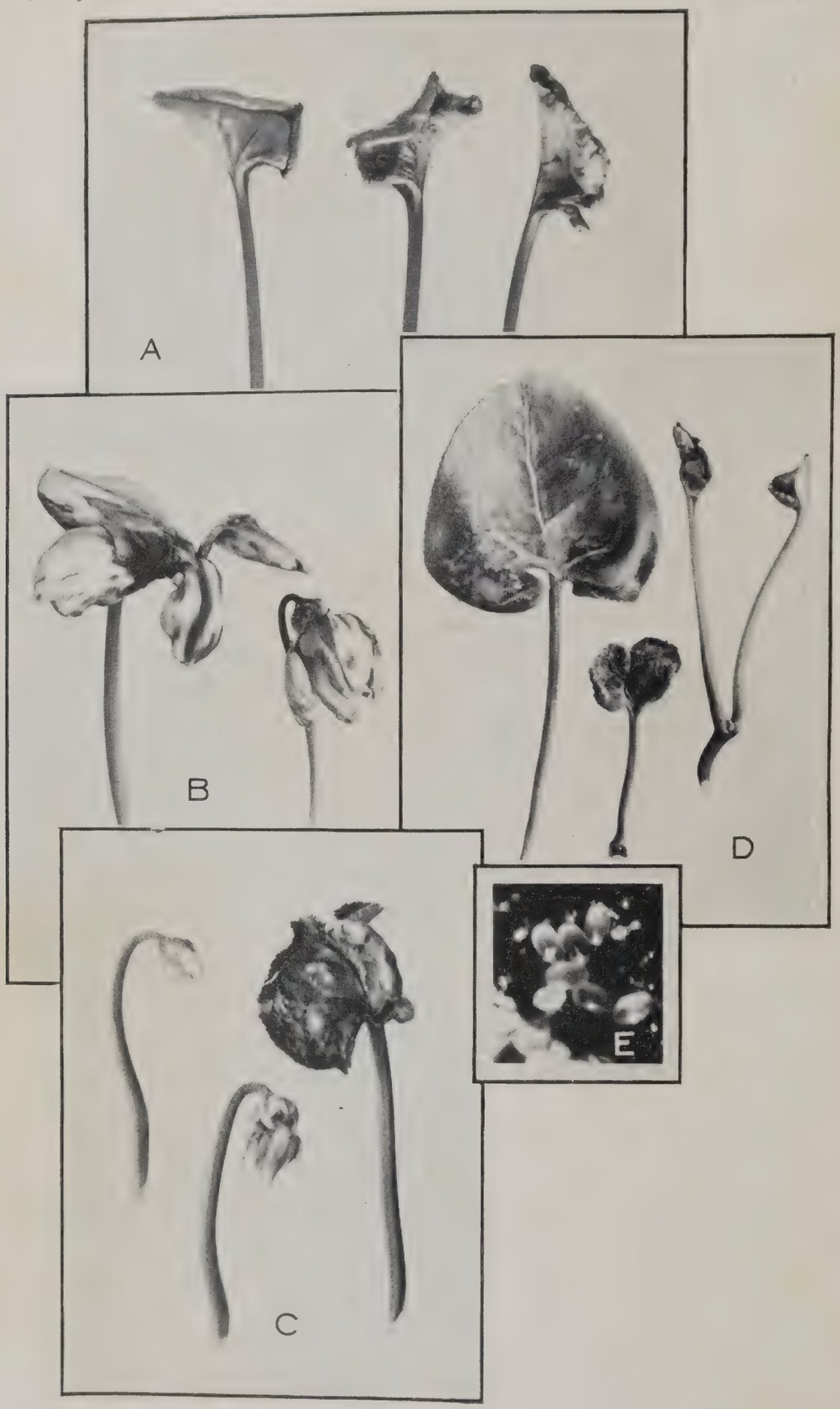

A
B
C
D
E

PLATE 52

A.—Cyclamen leaves showing the distortion to the leaves due to the attacks of the cyclamen mite.

B.—Cyclamen flowers showing the streaked parts due to attacks of the mites. This injury is usually accomplished in the young bud stage.

C.—A large cyclamen leaf, showing the curling and galling effect due to the mites, and young flower buds into the innermost parts of which the mites enter, resulting in the streaked flowers shown in figure B.

D.—Young cyclamen leaves with the peculiar curling due to attacks of the mites, together with an older leaf with a slight curling at the lobes caused by mite attacks while the leaf was young.

E.—A group of eggs of the cyclamen mite. Much enlarged. Original.

RELATION OF MOVEMENT OF WATER IN A SOIL TO ITS HYGROSCOPICITY AND INITIAL MOISTNESS[1]

By FREDERICK J. ALWAY, *Chief of Division of Soils*, and GUY R. MCDOLE, *Assistant in Soils, Agricultural Experiment Station of the University of Minnesota*

INTRODUCTION

The rate and distance of the capillary rise of water in soils have been determined in many laboratory investigations; but where the ground water is at a considerable distance below the surface, as is generally the case, these factors appear to be of little practical importance (2, p. 67).[2] In contrast with the capillary rise, the downward penetration of definite amounts of water has received very little attention. In the experiments on both subjects the soils have usually been employed in an air-dry state, a condition not met with in nature at depths below the surface few inches, as plant roots are not able to reduce the soil moisture to any such low point. In none of the experiments has the relative hygroscopicity of the soils been considered.

In the studies reported below we have considered both the hygroscopicity of the soils as expressed by their hygroscopic coefficients and their initial moistness. Most of them were employed in three moisture conditions—viz, with amounts of water equal to 0.5, 1, and 1.5 times the hygroscopic coefficient.

In the case of all our soils we have determined the moisture equivalents also, and in the discussion considered the relation of the movement of water in a soil to this value as well as to the hygroscopic coefficient. However, we give chief prominence to the latter, for the reason that the experiments were planned on the basis of the hygroscopic coefficients, the moisture equivalents being first determined only some time after the experiments had been completed, and for the additional reason that in our field studies only the hygroscopic coefficients had been determined. As the two values for any soil have been shown to bear a more or less definite relation to one another (6, p. 65; 3, p. 842), it is largely a matter of personal preference as to which is used as a single valued expression of soil texture.

Our viewpoint has been not that of the irrigationist nor that of the humid-land farmer with sharply rolling or sloping fields or an impervious soil causing losses through run-off, but that of the dry-land farmer whose crop returns depend chiefly upon the amount and the distribution of the precipitation. Our interest has lain not in the rate at which water can

[1] The work reported in this paper was carried out in 1912 and 1913 at the Nebraska Agricultural Experiment Station, where the authors were, respectively, Chemist and Research Assistant in Chemistry.

[2] Reference is made by number to "Literature cited," p. 427–428.

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be added to the surface without any run-off, but in the extent to which that from a light or moderate rain may be able to penetrate so deeply into the soil that it will later be exposed to only the minimum of loss through direct evaporation.

HISTORICAL REVIEW

Von Liebenberg (11, p. 31) and Atterberg (4, p. 113) appear to be the only investigators who have studied the downward movement in soils to which a definite depth of water had been applied and then allowed to penetrate as far as it would. Wollny (17, pp. 274, 288) carried out some experiments where the soils were contained in tubes covered with fine wire gauze and the water added drop by drop just as fast as it was absorbed, thus determining the rate of penetration when an unlimited amount of water is applied as rapidly as possible without actually losing any by run-off. In various experiments the rate of percolation has been studied, using a constant head of water, as 1 cm. in the work of Von Klenze (9, p. 113) and 4 cm. in that of Edler (7, p. 41).

Von Liebenberg (11, p. 31), using 22 surface soils to illustrate a wide range in texture, placed these in glass tubes of a diameter of 1.5 cm., added 1 inch of water, recorded the penetration after periods of one-fourth, one-half, one and one-half, four hours, one, two, and three days, and finally determined the distribution of moisture at intervals of 5 cm. and at the lower limit of penetration. He reports the mechanical analysis, the hygroscopic moisture, and the loss on ignition. The hygroscopic coefficients can not be computed (6, p. 69) from his mechanical analysis, as he separated his soils into only the four fractions, sand above 1 mm., sand 1 to 0.5 mm., sand under 0.5 mm., and "fine earth," without subdividing the last into silt and clay. In the case of the hygroscopic moisture the percentages he reports are clearly not those which would have been present had the soils all been in equilibrium with the atmosphere at the same time; accordingly they do not permit the computation of the relative hygroscopicities (1, p. 351). In fact, at least part of them seem far drier than would be expected if they had been exposed for a few days to the atmosphere of a storeroom or laboratory; thus, two loess samples contained only 1.81 and 1.22 per cent, respectively, of hygroscopic moisture (11, p. 13). In all his experiments he used the soils in this dry condition.

Our own experiments were in many respects very similar to those of Von Liebenberg, with whose work we were not acquainted until after we had completed our work. He, however, reports no data on the relative hygroscopicity of the soils he used and employed these in only a very dry form. He concluded that the penetration is dependent upon the "fine earth," it being less and taking place more slowly in soils with larger proportions of clay and organic matter.

Atterberg (4, pp. 113–124) determined the rate and distance of penetration during 1 to 6 days of different amounts of water, equivalent to

from 0.25 to 12 cm. rain, using various soil separates. As may be seen from those of his data assembled in Table I, he did not find any direct relation of the rate and distance of penetration to the fineness of texture.

TABLE I.—*Rate of capillary movement of water in sands and silts of different diameters, as found by Atterberg*

DISTANCE OF PENETRATION WHEN 5 CM. OF WATER WERE ADDED TO THE SURFACE[a]

Period.	Very fine sand (0.10–0.05 mm.).	Coarse silt (0.05–0.02 mm.).	Fine silt (0.02–0.01 mm.).
	Cm.	*Cm.*	*Cm.*
At end of 24 hours	17.4	19.2	17.2
At end of 2 days	18.0	20.5	18.0
At end of 3 days	18.5	21.7	18.2
At end of 4 days	.....	22.4	18.5

RISE OF WATER WHEN TUBES FILLED WITH MATERIAL WERE BROUGHT INTO CONTACT WITH WATER[b]

At end of 24 hours	53.0	115.3	48.5
At end of 2 days	57.4	136.0	92.2
At end of 3 days	60.2	146.6	131.8
At end of 4 days	62.9	153.1	153.6
At end of 5 days	65.0	157.5	168.9
At end of 18 days	96.6	177.4	209.5
At end of 30 days	100.0	.....	244.7

[a] 4, p. 119–120. [b] 4, p. 108.

Many studiss of the rate and distance of the upward movement of water have been made, in nearly all cases air-dry materials being employed. Among the earliest work on the subject we may mention that of Trommer (16, p. 268), Von Liebenberg (11, p. 22), Von Klenze (9), Edler (7), and Wollny (17).

Von Liebenberg used the same 22 soils and the same tubes as in the experiment mentioned above, making frequent observations of the rise during the first few hours and then daily for about 30 days, finally determining the distribution of water at intervals of 15 cm. and in the uppermost layer of the moistened portion of the soil column. He concluded that the more "fine earth," especially the more clay and organic matter, a soil contains, the higher is the final elevation attained, but the more slowly it takes place. The rise with the various soils in this experiment showed no definite relation to the penetration with the same soils in the other experiment.

Von Klenze (9), using glass tubes of an inner diameter of 3.5 cm., experimented with kaolin, peat, quartz, sand, marble dust, a loam, a sandy soil, a sand rich in organic matter and a calcareous sand, making frequent observations during the first 12 hours and after this daily for 9 or 10 days. He concluded that the rate of rise is affected most by the relative fineness of texture, it being slowest in the finest textured materials (9, p. 96–99).

Wollny (17) confirmed Von Klenze's observations, concluding that the finer the texture of the soil, the slower is the capillary movement, but the greater the distance reached before movement ceases.

Various later studies have in general confirmed Wollny's conclusions as to the relation of the rate and distance of upward capillary movement to the texture of the soil. (4, p. 107; 10; 12, p. 94; 14, p. 230; 15, p. 136). Atterberg (4, p. 108) reports data on the upward movement of water in sands and silts in which he determined also the rate of downward movement (Table I). The data obtained indicate no direct relation between the rates and distances in the opposite directions.

Grebe (8, p. 391), from a study of the moisture relations in a pine forest on a very sandy soil, concluded that—

> the elevation of ground-water does not make itself felt in sands and very fine sands beyond 1/3 meter and 1/2 meter, respectively.[1]

The only clues he furnishes as to the hygroscopicity of the soils in question are in the statements that in April when they were most moist they retained only from 3.66 to 4.61 per cent of water at various depths from 5 to 300 cm. below the surface and that the samples of the sand contained 41 to 48 per cent of particles under 0.3 mm. and 49 to 54 between 0.3 and 1.0 mm., while those of the fine sand contained 76 to 81 and 8 to 12, respectively (8, p. 390).

While the maximum final elevation of water is to be expected in the very fine textured soils, the rate is so slow that during an interval measured in days or weeks, or even in months, soils of intermediate texture show the greatest rise.

Data showing what relation the rate and final distance of rise bear to the actually determined hygroscopicity appear entirely wanting.

Less attention has been devoted to the influence of the initial moisture content. Wollny studied the influence of differences in the initial moisture content, using a loam powder and a pulverized calcareous sand rich in organic matter, each in five different moisture conditions—viz, (I) dried at 100° C., (II) air-dry, (III) exposed for several weeks to a saturated atmosphere, (IV) and (V) mixed with small amounts of water (17, p. 275). The soils were tamped into the tubes as compactly as possible and observations made for four or five days. In Table II we have assembled the portions of his data comparable with our own (reported in the experimental portion of this paper). Wollny concluded that the capillary movement in a soil increases with the moistness. To us his data do not appear to justify such a broad generalization. The loam in condition II (air-dry) showed practically the same upward movement as in the moister III, although with both there was a more rapid movement than with the oven-dried I; in IV, while the movement was more rapid than in I, II, or III, on the fifth day it practically overtook that in the moister V. With the other soil the rise was greatest in the air-dry form II, next in

[1] Translation.

the moistest (IV), then in III, nearly saturated, although least in the oven-dried material. It is probable that in III the initial moisture content approached but did not equal the hygroscopic coefficient, moisture from the saturated atmosphere being absorbed very slowly unless the exposed layer of soil is very thin; further, the ratio of hygroscopic moisture to water content is much lower than is to be expected from the coefficient (1, p. 353–356).

TABLE II.—*Rise of water (in centimeters) in two soils in different states of moistness showing influence of the moistness upon the rate of rise. Data of Wollny*

Time.	Experiment I (loam powder).					Experiment II (calcareous sand, pulverized).			
	I (dried at 100° C.).	II (air-dry).	III (approximately at the hygroscopic coefficient).	IV (mixed with water).	V (mixed with water).	I (dried at 100° C.).	II (air-dry).	III (approximately at the hygroscopic coefficient).	IV (mixed with water).
Initial moisture content, per cent	0	3.83	5.07	7.96	9.55	0	4.24	5.18	8.53
Hours.									
1	4.2	6.8	6.9	14.0	15.6	7.0	11.4	13.3	13.4
1¾	6.0	9.7	9.8	17.0	19.4	9.2	14.5	16.3	16.5
2¾	8.3	12.9	12.8	21.2	23.8	11.6	17.8	19.5	19.8
3¾	.....	.....	.....	.....	.....	14.7	20.5	22.0	22.3
4¼	10.4	15.6	15.5	25.1	28.0	.....	.....	.....	.....
24	23.9	36.5	36.7	52.0	54.7	30.9	41.4	40.6	41.8
48	30.8	51.4	51.6	66.5	68.5	40.7	52.0	48.6	51.0
72	39.8	60.7	60.9	76.5	77.3	47.4	58.0	52.9	55.9
96	52.0	69.2	69.6	83.4	84.5	56.0	65.4	58.0	62.1
120	60.6	76.2	76.7	90.7	91.6	.....	.....	.....	.....

Krakow (10, p. 210) determined the influence of the initial moisture content upon the rate of rise, using a sand in four different states of moistness—viz, with 0.21, 0.51, 1.18, and 2.39 per cent of water. The first was the air-dry sand. From our studies (1, p. 353–356) it would appear that we might estimate the hygroscopic coefficient of this as about 0.5 or 0.6, similar to the dune sand Q described in the experimental part of this paper. Krakow, continuing his observations for six days, found that after the fourth minute the rate of rise decreased with the moistness of the soil, the heights at the end of the sixth day being, respectively, 67.1, 42.4, 41.1, and 38.1 cm. The deviation of Krakow's findings from Wollny's conclusions Ramann (15, p. 334) attributes to increased friction due to inclosed bubbles of air.

Briggs and Lapham (5, p. 26), experimenting with a sandy soil whose hygroscopic coefficient computed (6, p. 69) from the mechanical analysis would be 2.81, concluded that when this was very moist the capillary rise was over four times as great as when the soil was dry. From experiments made by Mr. J. B. Stewart with three sands whose computed hydroscopic coefficients (6, p. 69) would be 0.7, 0.9, and 1.5, the same authors concluded that—

> no constant ratio exists between the capillary limits of soils in a dry and in a moist condition (5, p. 27).

From the above studies, involving only coarse soils and giving discordant results, no definite conclusions are to be drawn as to the effect of the initial moistness upon the movement of water.

NATURAL LOWER LIMIT OF MOISTURE IN THE SURFACE FOOT

We wished the moisture content of the soils used in our experiments to represent the lower limits naturally occurring in the surface foot in regions of limited rainfall. The lierature furnishes almost no data upon this subject, as a mere statement of the total moisture content is practically meaningless; it would be necessary to know the hygroscopic coefficient or the moisture equivalent, together with the total water, or the ratio of the last to one of the two constants. While the upper limit may be ascertained by sampling very soon after a heavy rain or irrigation, the lower limit in the field is to be found only after prolonged dry weather; and even in a semiarid region there may occur several successive years when conditions of drouth are not severe enough to induce the desired moisture conditions. From our field studies it would appear that in humid regions the moisture content of the whole surface foot is but rarely reduced to the hygroscopic coefficient, while in the semiarid regions this is not so unusual a phenomenon. In Tables IV and V we report data obtained in southwestern Nebraska in the spring of 1911, a time exceptionally favorable for such a field study, as the very dry crop season of the preceding year had been followed by a period of seven months—September 26 to April 25—in which the precipitation was almost negligible, the total rain and snow fall at the four places mentioned varying only from 0.85 to 3.45 inches (Table III).

TABLE III.—*Precipitation (in inches) at H. O. Ranch, Imperial, Wauneta, and McCook, Nebr., during the autumn, winter, and spring of 1910–11, a period of unusual drouth (Sept. 26, 1910, to Apr. 27, 1911)*

Date.	H, O. Ranch, near Madrid.	Imperial.	Wauneta.	McCook.	Date.	H. O, Ranch, near Madrid.	Imperial.	Wauneta.	McCook.
1910.					1911.				
September 1–25	1.28	1.58	3.20	0.72	February 28	T.	T.	.....	0.14
September 26–October 31	0	T.	0	.17	March 5	.....	0.10	.....	.....
November	.03	T.	.10	0	6	T.	.05	.....	.....
December	.14	.57	.85	.17	26	0.03	.07	.....	.12
1911.					27	.....	.....	0.50	.....
January 1	.....	.30	.....	.05	April 3	.....	.....	.75	.89
2	.03	.....	.....	.....	4	.04	.20	.....	.09
5	.....	.....	.10	.....	5	.05	.....	.....	.....
6	.....	.05	.....	.....	6	.....	.02	.....	.....
21	.12	.07	.....	.....	10	.....	T.	.....	.....
27	.....	T.	.....	.....	17	T.	T.	.35	.18
February 5	T.	T.	.....	.....	19	.....	.....	.05	.....
15	.....	.....	.40	.....	21	.....	T.	.....	.....
16	.....	.32	.20	.25	23	.....	.....	.05	.....
17	.31	T.	.....	.08	24	.05	.22	.....	.....
26	.....	T.	.10	.....	25	.18	.51	1.35	.42
27	T.	.05	.....	.....	26	.01	.....	.....	.....
					29	.....	.20	.65	.....
					30	1.61	1.40	.25	.14

During the last month of this dry period we took samples from the surface foot of over 50 fields in the vicinity of the four meteorological sta-

tions mentioned in the table. At a ranch near Madrid all were within half a mile of the rain gauge and at McCook within 4 miles; the other fields were between the neighboring stations, Wauneta and Imperial, which are about 15 miles apart, some nearer the former and the others nearer the latter. In each case the samples were composites from 10 individual samples taken not less than 10 yards apart. In most of the fields the surface foot was sampled only in 6-inch sections (Table IV), but 12 of them were sampled in 3-inch sections (Table V). The hygroscopic coefficients of the samples range from 1.9 to 14. The ratio of water content to coefficient is in general not far from unity, the lowest for the foot section being 0.7. In a few cases, as with fields 51, 52, and 53 (Table V), a light rain (Table III) had raised the ratio in the uppermost section; in fields 11 and 44 drifting snow, which had collected among the small trees during the winter, on melting had affected the moisture content.

TABLE IV.—*Ratio of the moisture content to the hygroscopic coefficient in the upper and lower halves of the surface foot in various fields in southwestern Nebraska in the spring of 1911*

Date.	Locality.	Field No.	Condition.	Hygroscopic coefficient.		Ratio.		
				1–6 in.	7–12 in.	1–6 in.	7–12 in.	1–12 in.
March 24	McCook	1	Prairie	8.4	10.9	0.9	0.8	0.8
25	do	2	do	8.4	9.1	.8	.9	.8
April 1	Wauneta	3	do	6.2	6.7	.8	.9	.8
3	do	4	do	7.4	9.3	1.0	.9	.9
12	Imperial	5	do	2.7	3.4	1.3	1.1	1.2
14	do	6	do	3.5	3.7	.7	.8	.7
15	Wauneta	7	do	9.0	9.0	1.0	.9	.9
15	do	8	do	8.7	8.6	1.1	.9	1.0
21	Madrid	9	do	9.0	8.9	.6	.8	.7
21	do	10	Prairie with young pines	2.0	2.2	1.1	1.1	1.1
21	do	11	do	1.9	1.9	2.0	2.0	2.0
6	Wauneta	12	Alfalfa	8.0	7.9	1.8	1.0	1.4
7	do	13	do	8.7	8.9	1.0	1.0	1.0
13	Imperial	14	do	3.4	4.2	.9	1.1	1.0
5	Wauneta	15	Winter wheat	6.8	6.8	1.1	.9	1.0
13	Imperial	16	do	2.7	3.8	1.2	1.5	1.3
14	do	17	do	1.7	2.4	1.1	1.6	1.3
20	Madrid	18	do	8.5	8.6	.7	1.2	.9
20	do	19	do	8.4	9.8	1.1	1.3	1.2
21	do	20	do	8.0	8.4	.8	1.2	1.0
6	Wauneta	21	Wheat stubble	5.1	6.8	1.4	1.1	1.2
7	do	22	do	12.1	14.4	.7	.9	.8
7	do	23	do	11.4	13.8	.9	.9	.9
8	do	24	do	7.7	7.9	.8	1.0	.9
10	do	25	do	5.0	5.6	1.1	1.0	1.0
11	Imperial	26	do	5.9	6.9	1.1	1.0	1.0
11	do	27	do	3.6	4.5	.9	1.2	1.1
15	Wauneta	28	do	8.3	9.3	1.1	.9	1.0
20	Madrid	29	do	4.8	6.6	.9	.9	.9
11	Imperial	30	Rye stubble	3.5	4.5	1.1	1.2	1.1
March 25	McCook	31	Kafir stubble	8.6	10.2	.9	1.0	.9
April 3	Wauneta	32	Cornstalks	6.4	7.3	1.0	1.0	1.0
8	do	33	do	6.5	9.0	.9	1.1	1.0
10	do	34	do	5.4	6.8	1.0	1.2	1.1
10	do	35	do	5.1	6.9	.8	1.0	.9
4	do	36	do	8.5	11.0	1.6	1.1	1.3
18	Imperial	37	do	2.1	4.9	1.7	1.4	1.5
18	do	38	do	2.6	3.2	1.7	1.6	1.6
10	do	39	do	2.1	4.1	1.5	1.6	1.5
11	do	40	do	3.5	4.2	1.9	1.8	1.8
March 30	McCook	41	Russian thistles	8.2	11.2	1.1	1.0	1.0
30	do	42	Milo stubble in orchard	5.6	8.5	1.2	1.1	1.1
29	do	43	do	8.1	9.4	1.1	1.2	1.1
April 20	Madrid	44	Locust grove	8.2	11.4	1.7	1.2	1.4
March 27	McCook	45	Orchard	9.3	9.3	1.4	1.3	1.3
29	do	46	Fallow	8.7	9.7	1.3	1.6	1.4
April 13	Imperial	47	do	3.7	5.0	1.2	1.5	1.3

In eastern Nebraska we did not find such a low ratio in the first foot. Throughout the season of 1912 a field of bluegrass close to the Experiment Station at Lincoln was kept under close observation, the surface foot at frequent intervals being sampled in 1 inch sections. After two or three weeks of dry, hot weather the ratio would fall as low as 1.1 to 1.3, but not lower (2, p. 59).

TABLE V.—*Ratio of moisture content to the hygroscopic coefficient in the different portions of the surface foot of various fields in western Nebraska in the spring of 1911*

Date.	Locality.	Field No.	Condition.	Hygroscopic coefficient.				Ratio.			
				1–3 in.	4–6 in.	7–9 in.	10–12 in.	1–3 in.	4–6 in.	7–9 in.	10–12 in.
March 25.	McCook.....	48	Kafir corn.....	8.4	8.8	9.5	9.9	0.6	0.9	1.0	1.1
25.	.....do.....	49	Milo.....	7.0	7.6	8.0	8.9	.7	.9	1.0	1.0
30.	.....do.....	50	Russian thistles..	7.8	8.2	9.4	10.0	.7	1.0	1.0	.9
April 4...	Wauneta....	51	Cornstalks.....	9.4	9.5	9.6	9.7	1.8	.9	1.0	1.0
4...	.....do.....	52	.....do.....	10.1	10.1	10.1	10.7	1.8	1.0	.9	1.0
4...	.....do.....	53	.....do.....	9.8	9.7	9.8	9.7	1.5	.9	.9	1.0
1...	Imperial.....	54	.....do.....	6.5	7.2	7.1	7.2	1.4	1.6	1.3	1.2
1...	.....do.....	55	.....do.....	5.7	6.1	6.6	7.1	.6	1.0	1.0	1.0
1...	.....do.....	56	.....do.....	3.9	4.4	5.6	6.2	.8	1.4	1.4	1.2
3...	.....do.....	57	.....do.....	3.5	4.4	4.3	4.4	.8	1.5	2.1	1.3
3...	.....do.....	58	.....do.....	2.2	4.0	5.1	6.2	.9	1.6	1.5	1.3
3...	.....do.....	59	.....do.....	2.8	3.4	4.7	5.1	.8	1.7	1.7	1.7

CHARACTER OF THE SOILS USED

Seventeen soils in all were used in the experiments, twelve of these being identical with those described in a previous paper (2, p. 32). Twelve were from Nebraska, two from New Mexico, one from Arizona, and two from the southern end of the Colorado Desert in California. Instead of being selected to cover the whole range in texture from clays to coarse sands the Nebraska soils were intended to represent some of the most important types in that State, while to each of those from other States an unusual interest attaches because of their behavior in their natural position in the field.

Soils A, C, D, E, G, and H are silt loams from the loess; I, J, K, L, and M are residual soils from western Nebraska; and Q is a dune sand from a "blow-out" in the Nebraska sand-hill region.

Soil F, from Cuervo, in northeastern New Mexico, is a residual soil derived from the red beds. In its natural position this soil offers such great resistance to the downward movement of moisture that the water from a heavy shower was found in small pools on the surface, while only 12 inches below the bottom of the pools 20 hours after the shower the soil was still as dry as powder. Soil N is a red sand from Orogrande in the Tularosa Desert in southern New Mexico; and N, a fine-textured alluvial soil from near Douglas, Arizona, is typical of those deep soils of the Southwest which fail to accumulate moisture through summer fallowing. D is a subsoil from the abandoned Pope olive orchard described by

Mason (13, pp. 20–23), at Palm Springs, California, and P is from sand drifts in the Whitewater Wash adjacent to Palm Springs station.

In Table VI are reported the total nitrogen, the organic carbon as determined by combustion with copper oxid in a current of oxygen after treatment with a phosphoric-acid solution and subsequent evaporation to dryness, and the organic matter, as well as the hygroscopic coefficient, the moisture equivalent, and the maximum water capacity as determined by Hilgard's method.

TABLE VI.—*Composition and physical properties of soils used in the experiments*

Soil.	Total nitrogen.	Organic carbon.	Organic matter.[a]	Hygroscopic coefficient.	Moisture equivalent.	Ratio of moisture equivalent to hygroscopic coefficient.	Maximum water capacity.
Loess soil from near Lincoln, Nebr.:	*Per cent.*	*Per cent.*	*Per cent.*				*Per cent.*
Surface D	0.244	2.86	4.93	10.2	27.8	2.73	60.9
Subsoil A	.049	.36	.62	13.3	29.5	2.22	65.7
Loess soil from near McCook, Nebr.:							
Surface C	.104	1.23	2.12	10.5	24.1	2.30	63.7
Subsoil G	.029	.35	.60	8.2	21.2	2.59	55.4
Loess soil from near Culbertson, Nebr.:							
Surface E	.079	.90	1.55	10.1	22.5	2.23	56.8
Subsoil H	.018	.32	.55	7.6	19.7	2.59	57.2
"Hard land" from near Imperial, Nebr.:							
Surface I	.106	1.07	1.84	7.1	16.8	2.37	53.4
Subsoil K	.016	.17	.29	3.4	7.5	2.21	36.0
"Sandy land" from near Imperial, Nebr.:							
Surface M	.077	.71	1.22	3.3	7.9	2.39	34.2
Subsoil L	.023	.17	.29	3.4	7.2	2.12	31.0
"Hard land" from near Madrid, Nebr.:							
Subsoil J	.021	.28	.48	5.6	13.5	2.41	46.3
Dune sand from near Dunning, Nebr.:							
Subsoil Q	.008	.05	.08	.6	1.5	2.50	25.8
Black adobe from near Douglas, Ariz.:							
Surface B	.088	1.29	2.22	12.9	25.8	2.00	60.3
Red loam from Cuervo, N. Mex.:							
Surface F	.072	.62	1.07	10.0	19.2	1.92	49.0
Red desert sand from Orogrande, N. Mex.:							
Surface N	.020	.20	.34	1.7	3.0	1.76	27.1
Sand from Pope orchard, Palm Springs, Cal.:							
Subsoil O	(b)	(b)	(b)	.9	1.6	1.77	28.9
Gray desert sand from Palm Springs Station, Cal.:							
Surface P	(b)	(b)	(b)	1.1	2.8	2.54	27.0

[a] Organic matter = Organic C × 1.724. [b] These samples were lost before the analyses had been made.

DOWNWARD MOVEMENT IN SOILS DIFFERING IN INITIAL WATER CONTENT

EXPERIMENTS

There were three subexperiments, which differed from one another only in the initial moisture content of the soils, it being approximately 0.5, 1.0, and 1.5 times the hygroscopic coefficient, respectively (Table VII). The first would represent the lower limit of moisture in exposed surface soils after a prolonged drouth during hot weather; the second would correspond to the condition found just after a very heavy crop had matured during warm, dry weather and so had had an opportunity to exhaust fully the available soil moisture; while the last would represent that moisture content at which very shallow-rooted plants might be expected to begin to suffer permanent wilting—the wilting coefficient as defined by Briggs and Shantz (6, p. 9).

All the soils mentioned in Table VI were used, with glass cylinders 14.24 inches (36.2 cm.) high and 3.07 inches (7.8 cm.) in internal diameter. To bring the soil to the desired moisture content, a weighed quantity of air-dried material, of which the moisture content had previously been determined, was placed upon a large sheet of oilcloth on the floor of the mixing room, and while the mass was being shoveled over, the calculated amount of water was added in small portions. The whole was then mixed thoroughly, first by shoveling, then by passing it twice through a swinging sieve of ¼-inch mesh, and finally by again shoveling, after which it was immediately placed in a large covered can, allowed to stand for several days, again passed through the swinging sieve, returned to the can, and kept in it until transferred to the cylinders.

In filling the cylinders the soil was added very slowly with constant tamping, care being taken to insure the firmness of that already in before adding more. Blows as uniform as possible were delivered by means of a tamper consisting of a 2-inch rubber stopper on the end of a ⅜-inch iron gas pipe 3 feet long.

One inch of water was added to the surface of each of the cylinders. In order to make the initial penetration of the water more uniform, the cylinders were inverted in flat-bottomed metal trays, the desired amount of water was added and was allowed to rise into the soil by capillarity until all or nearly all had been absorbed, after which they were placed right side up and covered to prevent evaporation.

In each of the three experiments the water was applied to all the cylinders at practically the same time, they having been filled and inverted in the trays and the measured quantity of water required for each placed beside it in a beaker. To facilitate the escape of the air expelled by the entering water, a fine wire was placed under the edge of the cylinder. Then the beakers were emptied into the trays as

quickly as possible. As soon as the water in the trays had disappeared, the cylinders were righted. All was absorbed by capillarity except that with the coarsest sands, and, in the case of these, the small volume of water remaining, 10 to 15 c. c., was added to the surface after the cylinders had been righted. Protected from evaporation and direct sunlight, they were allowed to stand for five days, during which time, at intervals of 1, 3, and 24 hours, 2, 3, 4, and 5 days, the depth of penetration of the water was marked on the cylinders by means of a fat pencil. In the first and second experiments the depth of penetration was distinctly indicated by the change in color of the soil, but with the moister soils of the third experiment the exact depth of penetration was much more difficult to recognize, a fact to which Wollny has called attention (17, p. 278–279); and with soils B and D it soon became impossible. The data are reported in Table VIII. The initial water content in the three experiments I, II, and III was approximately 0.5, 1.0, 1.5 times the hygroscopic coefficient, respectively. Although we actually recorded the measurements of the distance of penetration in millimeters, the data are given in inches so as to permit a readier comparison with field moisture data as ordinarily reported in this country.

TABLE VII.—*Initial moisture condition of the soil in the different experiments*

Soil No.	Hygroscopic coefficient.	Moisture content			Ratio of moisture content to hygroscopic coefficient.		
		Experiment I	Experiment II	Experiment III	Experiment I	Experiment II	Experiment III
		P. ct.	*P. ct.*	*P. ct.*			
A	13.3	6.6	13.4	20.1	0.5	1.0	1.5
B	12.9	6.3	13.0	21.6	.5	1.0	1.7
C	10.5	5.0	11.1	15.8	.5	1.1	1.
D	10.2	4.9	10.1	15.7	.5	1.0	1.
E	10.1	5.0	10.3	15.4	.5	1.0	1.
F	10.0	4.8	10.2	15.2	.5	1.0	1.
G	8.2	3.9	8.0	12.4	.5	1.0	1.
H	7.6	3.8	7.9	11.2	.5	1.0	1.
I	7.1	3.5	7.5	10.4	.5	1.1	1.
J	5.6	2.8	5.3	8.3	.5	.9	1.
K	3.4	1.7	3.7	4.8	.5	1.1	1.
L	3.4	1.6	3.5	5.0	.5	1.0	1.
M	3.3	1.7	3.7	4.9	.5	1.1	1.
N	1.7	.6	.....	.....	.4	.....	...
O	1.1	.6	.....	.....	.5	.....	...
P	.9	.4	.....	.....	.4	.....	...
Q	.6	.2	.....	.....	.3	.....	...

TABLE VIII.—*Moisture relations at end of increasing periods of time following an application of 1 inch of water to the surface*

SOIL A (HYGROSCOPIC COEFFICIENT = 13.3. INITIAL MOISTURE CONTENT: I, 6.6 PER CENT; II, 13.4 PER CENT; III, 20.1 PER CENT)

Time.	Distance of penetration of added water.			Water content of the moistened portion.			Ratio of water content of the moistened portion to hygroscopic coefficient.		
	Experiment I.	Experiment II.	Experiment III.	Experiment I.	Experiment II.	Experiment III.	Experiment I.	Experiment II.	Experiment III.
Hours.	*Inches.*	*Inches.*	*Inches.*	*Per ct.*	*Per ct.*	*Per ct.*			
1	2.40	2.60	5.08	38.8	45.5	37.0	2.9	3.4	2.8
3	3.03	4.83	7.56	32.2	30.7	31.4	2.4	2.3	2.4
24	3.82	6.18	10.12	26.9	27.0	28.6	2.0	2.0	2.1
48	4.02	6.53	10.66	25.9	26.2	28.4	1.9	2.0	2.1
72	4.02	6.70	11.18	25.9	25.9	27.7	1.9	1.9	2.1
96	4.02	6.72	11.46	25.9	25.8	27.5	1.9	1.9	2.1
120	4.02	6.93	11.66	25.9	24.5	27.4	1.9	1.8	2.1

SOIL B (HYGROSCOPIC COEFFICIENT = 12.9. INITIAL MOISTURE CONTENT: I, 6.3 PER CENT; II, 13.0 PER CENT; III, 21.6 PER CENT)

1	1.85	2.32	3.94	50.2	48.9	43.6	3.9	3.8	3.4
3	2.87	3.94	6.14	34.8	34.2	35.7	2.7	2.7	2.8
24	4.02	6.34	[a] 8.08	26.5	26.2	[a] 32.3	2.1	2.0	[a] 2.5
48	4.21	7.01	.....	25.6	24.9	.....	2.0	1.9	.....
72	4.41	7.32	.....	24.7	24.4	.....	1.9	1.9	.....
96	4.65	7.44	.....	23.8	24.2	.....	1.8	1.9	.....
120	4.65	7.60	.....	23.8	23.9	.....	1.8	1.8	.....

SOIL C (HYGROSCOPIC COEFFICIENT = 10.5. INITIAL MOISTURE CONTENT: I, 5.0 PER CENT; II, 11.1 PER CENT; III, 15.8 PER CENT)

1	3.31	4.12	5.31	29.5	31.5	32.6	2.8	3.0	3.1
3	3.70	4.84	6.50	26.9	27.8	29.5	2.5	2.5	2.7
24	4.37	6.10	8.58	23.6	24.8	26.1	2.2	2.4	2.5
48	4.51	6.50	9.33	23.0	24.1	25.5	2.2	2.3	2.4
72	4.80	6.77	9.69	21.8	23.7	25.0	2.1	2.3	2.4
96	4.80	6.93	10.00	21.8	23.4	24.7	2.1	2.2	2.3
120	4.80	7.01	10.35	21.8	23.0	24.4	2.1	2.2	2.3

SOIL D (HYGROSCOPIC COEFFICIENT = 10.2. INITIAL MOISTURE CONTENT: I, 4.9 PER CENT; II, 10.1 PER CENT; III, 15.7 PER CENT)

1	2.40	3.07	3.62	39.2	37.9	40.5	3.8	3.7	4.0
3	2.91	4.17	5.35	33.0	30.8	32.4	3.2	3.0	3.2
24	3.90	5.39	7.44	26.2	26.1	27.8	2.6	2.6	2.7
48	4.12	5.82	7.83	24.9	24.9	27.1	2.4	2.4	2.6
72	4.21	5.98	8.23	24.2	24.5	26.5	2.4	2.4	2.6
96	4.21	6.14	8.50	24.2	24.2	26.2	2.4	2.4	2.6
120	4.21	6.30	8.86	24.2	23.8	26.0	2.4	2.3	2.5

SOIL E (HYGROSCOPIC COEFFICIENT = 10.1. INITIAL MOISTURE CONTENT: I, 5.0 PER CENT; II, 10.3 PER CENT; III, 15.4 PER CENT)

1	3.15	3.91	5.04	29.8	31.7	32.5	2.9	3.1	3.2
3	3.50	5.08	6.85	27.4	26.8	28.3	2.7	2.6	2.8
24	4.45	6.65	8.78	22.7	23.2	26.0	2.2	2.3	2.5
48	4.80	7.24	9.21	21.5	22.0	25.0	2.1	2.2	2.5
72	4.96	7.64	9.57	21.0	21.3	24.6	2.1	2.1	2.4
96	5.00	7.99	9.80	20.8	20.9	24.4	2.1	2.1	2.4
120	5.00	8.23	9.96	20.8	20.4	24.2	2.1	2.0	2.4

[a] On account of the color of the soil, the advance of the moisture beyond this point could not be followed.

TABLE VIII.—*Moisture relations at end of increasing periods of time following an application of 1 inch of water to the surface*—Continued

SOIL F (HYGROSCOPIC COEFFICIENT = 10.0. INITIAL MOISTURE CONTENT: I, 4.8 PER CENT; II, 10.2 PER CENT; III, 15.2 PER CENT)

Time.	Distance of penetration of added water.			Water content of the moistened portion.			Ratio of water content of the moistened portion to hygroscopic coefficient.		
	Experiment I.	Experiment II.	Experiment III.	Experiment I.	Experiment II.	Experiment III.	Experiment I.	Experiment II.	Experiment III.
Hours.	*Inches.*	*Inches.*	*Inches.*	*Per ct.*	*Per ct.*	*Per ct.*			
1	2.48	4.17	5.12	33.8	29.2	31.4	3.3	2.9	3.1
3	3.11	5.32	7.64	27.9	25.1	26.0	2.7	2.5	2.6
24	4.37	7.17	[a] 8.82	21.3	21.2	[a] 25.2	2.1	2.1	[a] 2.5
48	4.57	7.79	.....	20.4	20.4	.....	2.0	2.0	.....
72	5.00	8.15	.....	19.2	19.9	.....	1.9	2.0	.....
96	5.00	8.39	.....	19.2	19.6	.....	1.9	2.0	.....
120	5.00	8.66	.....	19.2	19.4	.....	1.9	1.9	.....

SOIL G (HYGROSCOPIC COEFFICIENT = 8.2. INITIAL MOISTURE CONTENT: I, 3.9 PER CENT; II, 8.0 PER CENT; III, 12.4 PER CENT)

1	3.11	3.97	5.63	28.6	28.0	27.5	3.5	3.4	3.4
3	3.58	4.84	6.89	25.3	24.4	24.8	3.1	3.0	3.0
24	4.76	6.50	8.78	19.6	20.1	22.3	2.4	2.4	2.7
48	5.16	7.24	9.09	18.8	18.6	22.0	2.3	2.3	2.7
72	5.39	7.64	9.45	18.1	18.4	21.6	2.2	2.2	2.6
96	5.63	7.99	9.64	17.5	17.9	21.4	2.1	2.2	2.6
120	5.63	8.23	9.84	17.5	17.7	21.2	2.1	2.2	2.6

SOIL H (HYGROSCOPIC COEFFICIENT = 7.6. INITIAL MOISTURE CONTENT: I, 3.8 PER CENT; II, 7.9 PER CENT; III, 11.2 PER CENT)

1	3.15	4.02	5.20	28.4	28.5	27.9	3.7	3.8	3.7
3	3.43	4.92	6.42	26.3	24.7	24.2	3.5	3.2	3.1
24	4.76	6.65	8.78	20.2	20.3	21.1	2.7	2.7	2.8
48	5.12	7.28	9.37	18.9	19.2	20.4	2.5	2.5	2.7
72	5.35	7.64	9.76	18.2	18.7	20.0	2.4	2.5	2.6
96	5.59	8.03	9.96	17.7	18.2	19.8	2.3	2.4	2.6
120	5.59	8.27	10.16	17.7	17.9	19.3	2.3	2.4	2.5

SOIL I (HYGROSCOPIC COEFFICIENT=7.1. INITIAL MOISTURE CONTENT: I, 3.5 PER CENT; II, 7.5 PER CENT; III, 10.4 PER CENT)

1	3.58	4.06	4.72	25.7	29.1	28.0	3.6	4.1	3.9
3	3.82	4.84	5.79	24.3	25.5	24.7	3.4	3.6	3.5
24	4.49	6.22	7.83	21.1	21.6	21.0	3.0	3.0	3.0
48	4.88	6.73	8.31	19.7	20.5	20.4	2.8	2.9	2.9
72	5.04	7.01	8.70	19.2	20.0	20.0	2.7	2.8	2.8
96	5.04	7.09	8.94	19.2	19.9	19.7	2.7	2.8	2.8
120	5.04	7.40	9.09	19.2	19.3	19.3	2.7	2.7	2.7

SOIL J (HYGROSCOPIC COEFFICIENT=5.6. INITIAL MOISTURE CONTENT: I, 2.8 PER CENT; II, 5.3 PER CENT; III, 8.3 PER CENT)

1	3.70	4.21	6.06	22.8	22.7	21.4	4.1	3.9	3.8
3	4.09	5.08	7.32	20.9	19.7	19.2	3.7	3.4	3.4
24	5.51	6.73	10.28	16.2	16.1	16.0	2.9	2.9	2.9
48	5.83	7.44	11.10	15.3	15.1	15.5	2.7	2.7	2.8
72	6.10	7.95	11.53	14.9	14.7	15.2	2.7	2.6	2.7
96	6.42	8.42	11.77	14.3	14.0	15.1	2.6	2.5	2.7
120	6.61	8.74	12.01	14.0	13.4	14.9	2.5	2.4	2.7

[a] On account of the color of the soil, the advance of the moisture beyond this point could not be followed.

TABLE VIII.—*Moisture relations at end of increasing periods of time following an application of 1 inch of water to the surface*—Continued

SOIL K (HYGROSCOPIC COEFFICIENT=3.4. INITIAL MOISTURE CONTENT: I, 1.7 PER CENT; II, 3.7 PER CENT III, 4.8 PER CENT)

Time.	Distance of penetration of added water.			Water content of the moistened portion.			Ratio of water content of the moistened portion to hygroscopic coefficient.		
	Experiment I.	Experiment II.	Experiment III.	Experiment I.	Experiment II.	Experiment III.	Experiment I.	Experiment II.	Experiment III.
Hours.	*Inches.*	*Inches.*	*Inches.*	*Per ct.*	*Per ct.*	*Per ct.*			
1	3.39	3.35	4.88	21.8	24.7	19.7	6.4	7.3	5.8
3	3.58	4.72	6.30	20.5	18.3	16.3	6.0	5.4	4.8
24	4.84	6.81	8.34	15.8	13.8	13.4	4.6	4.1	3.9
48	5.35	7.60	9.02	14.5	12.9	12.9	4.3	3.8	3.8
72	5.71	8.11	9.53	13.7	12.4	12.4	4.0	3.6	3.6
96	5.94	8.50	9.80	13.2	11.9	12.2	3.9	3.5	3.6
120	6.18	8.90	10.00	12.7	11.4	12.1	3.7	3.4	3.6
SOIL L (HYGROSCOPIC COEFFICIENT = 3.4. INITIAL MOISTURE CONTENT: I, 1.6 PER CENT; II, 3.5 PER CENT; III, 5 PER CENT)									
1	4.13	4.96	7.40	16.9	17.0	14.2	5.0	5.0	4.2
3	4.64	6.50	9.49	15.2	13.8	12.2	4.5	4.1	3.6
24	6.73	9.33	[a] 13.78	11.0	10.7	[a] 10.0	3.2	3.1	[a] 2.9
48	7.20	10.20	.....	10.4	10 2	.....	3.1	3.0	.....
72	7.40	10.39	.....	10.1	10.1	.....	3.0	3.0	.....
96	7.64	11.30	.....	10.0	9.4	.....	2.9	2.8	.....
120	7.83	11.69	.....	9.7	9.2	.....	2.9	2.7	.....
SOIL M (HYGROSCOPIC COEFFICIENT=3.3. INITIAL MOISTURE CONTENT: I, 1.7 PER CENT; II, 3.7 PER CENT; III, 4.9 PER CENT)									
1	4.05	3.70	5.43	18.4	22.5	17.8	5.6	6.8	5.4
3	4.29	5.20	6.73	17.6	17.2	15.3	5.3	5.2	4.6
24	5.04	6.57	8.74	15.2	14.3	12.9	4.6	4.3	3.9
48	5.28	6.93	9.49	14.7	13.7	12.3	4.5	4.1	3.7
72	5.39	7.16	9.92	14.4	13.5	12.0	4.4	4.1	3.6
96	5.63	7.36	10.16	13.8	13.1	11.8	4.2	4.0	3.6
120	5.63	7.52	10.35	13.8	12.9	11.7	4.2	3.9	3.5
SOIL N (HYGROSCOPIC COEFFICIENT=1.6. INITIAL MOISTURE CONTENT: 0.6 PER CENT)									
1	5.12	.....	.....	12.8	.....	.....	8.0	.....	.....
3	5.51	.....	.....	11.9	.....	.....	7.4	.....	.....
24	6.85	.....	.....	9.7	.....	.....	6.0	.....	.....
48	7.48	.....	.....	8.9	.....	.....	5.5	.....	.....
72	8.07	.....	.....	8.3	.....	.....	5.2	.....	.....
96	8.46	.....	.....	8.0	.....	.....	5.0	.....	.....
120	8.78	.....	.....	7.7	.....	.....	4.8	.....	.....
SOIL O (HYGROSCOPIC COEFFICIENT=1.1. INITIAL MOISTURE CONTENT: 0.6 PER CENT)									
1	5.12	.....	.....	11.7	.....	.....	10.6	.....	.....
3	6.10	.....	.....	9.9	.....	.....	9.0	.....	.....
24	8.35	.....	.....	7.3	.....	.....	6.6	.....	.....
48	9.09	.....	.....	7.0	.....	.....	6.3	.....	.....
72	9.61	.....	.....	6.6	.....	.....	6.0	.....	.....
96	10.00	.....	.....	6.5	.....	.....	5.9	.....	.....
120	10.31	.....	.....	6.2	.....	.....	5.6	.....	.....
SOIL P (HYGROSCOPIC COEFFICIENT=0.9. INITIAL MOISTURE CONTENT: 0.4 PER CENT)									
1	4.92	.....	.....	13.0	.....	.....	14.4	.....	.....
3	5.79	.....	.....	11.0	.....	.....	12.2	.....	.....
24	6.73	.....	.....	9.7	.....	.....	10.8	.....	.....
48	7.76	.....	.....	8.5	.....	.....	9.4	.....	.....
72	8.86	.....	.....	7.6	.....	.....	8.4	.....	.....
96	9.29	.....	.....	7.2	.....	.....	8.0	.....	.....
120	9.84	.....	.....	6.6	.....	.....	7.3	.....	.....

[a] On account of the color of the soil, the advance of the moisture beyond this point could not be followed.

In the first and second experiments we used three cylinders of each soil and in the third two. As in the previously reported experiments (2, p. 34), the final moisture conditions as well as the rate of movement were so similar in the duplicates and triplicates that only the averages are reported. As illustrations of the degree of concordance, data from the individual cylinders of three soils are reported in Table IX.

TABLE IX.—*Data on three soils, illustrating the concordance of the data from triplicate cylinders*

WEIGHT OF MOIST SOIL IN CYLINDERS (IN GRAMS)

Item.	Soil D.			Soil H.			Soil L.		
	Cylinder I.	Cylinder II.	Cylinder III.	Cylinder I.	Cylinder II.	Cylinder III.	Cylinder I.	Cylinder II.	Cylinder III.
Experiment I	2,154	2,196	2,183	2,254	2,325	2,325	2,793	2,750	2,707
Experiment II	2,196	2,211	2,183	2,240	2,240	2,211	2,636	2,650	2,650
Experiment III	2,196	2,225	.....	2,169	2,225	.....	2,565	2,679	.....

DEPTH OF PENETRATION (IN INCHES)

Experiment I (initial moisture content=0.5 hygroscopic coefficient):									
1 hour	2.52	2.28	2.40	3.30	3.11	2.99	3.38	4.49	4.49
3 hours	2.99	2.79	2.99	3.50	3.50	3.31	4.01	4.88	4.99
24 hours	3.82	3.82	4.01	4.88	4.88	4.49	6.30	6.81	7.09
48 hours	4.01	4.01	4.08	4.99	5.32	4.99	6.81	7.29	7.52
72 hours	4.28	4.08	4.28	5.12	5.59	5.32	7.00	7.60	7.60
96 hours	(a)	(a)	(a)	5.51	5.78	5.51	7.29	7.79	7.79
120 hours	(a)	(a)	(a)	(a)	(a)	(a)	7.52	7.99	7.99
Experiment II (initial moisture content=1.0 hygroscopic coefficient):									
1 hour	3.46	3.26	2.48	3.78	4.17	4.13	3.67	5.32	3.94
3 hours	4.41	4.33	3.82	4.96	4.92	4.92	6.89	6.81	5.78
24 hours	5.51	5.51	5.11	6.54	6.77	6.61	9.61	9.45	8.97
48 hours	6.02	5.78	5.63	7.21	7.33	7.29	10.48	10.24	9.84
72 hours	6.17	6.02	5.78	7.48	7.87	7.60	11.02	10.79	10.48
96 hours	6.38	6.10	5.98	8.03	8.18	7.87	11.62	11.29	11.02
120 hours	6.46	6.30	6.10	8.27	8.47	8.07	12.01	11.81	11.29

(a) No movement.

At the end of the period of observation the soil was removed from the cylinders and the moisture determined. In the first and second experiments the moistened portion was divided into three equal sections, in each of which the moisture was separately determined. The first inch of dry soil, that immediately below the depth to which the change in color indicated that the water had penetrated, was used as the fourth section. In the third experiment, as the dividing line was in most cases indistinct, the whole soil column was divided into four equal sections, the fourth being that next the bottom of the cylinder. The data showing the distribution of moisture when the cylinders were opened are reported in Table X.

TABLE X.—*Distribution of moisture and its relation to the hygroscopic coefficient 5 days after the application of 1 inch of water to the surface*

SOIL A (HYGROSCOPIC COEFFICIENT=13.3. INITIAL MOISTURE CONTENT: I, 6.6 PER CENT; II, 13.4 PER CENT; III, 20.1 PER CENT)

Section.	Water content.			Ratio of water content to hygroscopic coefficient.		
	Experiment I.	Experiment II.	Experiment III.	Experiment I.	Experiment II.	Experiment III.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1	24.6	26.8	27.6	1.8	2.0	2.1
2	23.0	24.3	26.0	1.7	1.8	2.0
3	19.1	21.8	24.3	1.4	1.6	1.8
Average, 1–3	22.2	24.3	26.0	1.7	1.8	1.9
4[a]	10.6	15.2	21.0	.8	1.1	1.6

SOIL B (HYGROSCOPIC COEFFICIENT=12.9. INITIAL MOISTURE CONTENT: I, 6.3 PER CENT; II, 13.0 PER CENT; III, 21.6 PER CENT)

1	22.2	24.4	29.0	1.7	1.9	2.2
2	21.2	22.2	28.0	1.6	1.7	2.2
3	19.0	19.4	26.2	1.5	1.5	2.0
Average, 1–3	20.8	22.0	27.7	1.6	1.7	2.1
4	11.0	14.2	25.8	.9	1.1	2.0

SOIL C (HYGROSCOPIC COEFFICIENT=10.5. INITIAL MOISTURE CONTENT: I, 5.0 PER CENT; II, 11.1 PER CENT; III, 15.8 PER CENT)

1	23.3	22.9	27.3	2.2	2.2	2.6
2	21.4	20.8	22.7	2.0	2.0	2.2
3	18.1	17.4	19.7	1.7	1.7	1.9
Average, 1–3	20.9	20.4	23.2	2.0	2.0	2.2
4	8.3	10.6	15.8	.....	1.0	1.5

SOIL D (HYGROSCOPIC COEFFICIENT=10.2. INITIAL MOISTURE CONTENT: I, 4.9 PER CENT; II, 10.1 PER CENT; III, 15.7 PER CENT)

1	26.4	25.5	26.7	2.6	2.5	2.6
2	23.6	22.6	23.3	2.3	2.3	2.3
3	19.4	17.6	17.1	1.9	1.7	1.7
Average, 1–3	23.1	21.9	22.4	2.3	2.1	2.2
4	7.2	10.3	15.5	.7	1.0	1.5

SOIL E (HYGROSCOPIC COEFFICIENT=10.1. INITIAL MOISTURE CONTENT: I, 5.0 PER CENT; II, 10.3 PER CENT; III, 15.4 PER CENT)

1	20.1	21.3	23.1	2.0	2.1	2.3
2	19.0	19.7	22.0	1.9	2.0	2.2
3	15.4	15.7	20.3	1.5	1.6	2.0
Average, 1–3	18.2	18.9	21.8	1.8	1.9	2.2
4	6.8	10.5	17.8	.7	1.0	1.8

[a] In experiments I and II this section consists of the 1-inch layer immediately below the moistened layer, while in experiment III it is the lowest quarter of the soil column.

TABLE X.—*Distribution of moisture and its relation to the hygroscopic coefficient 5 days after the application of 1 inch of water to the surface*—Continued

SOIL F (HYGROSCOPIC COEFFICIENT=10.0. INITIAL MOISTURE CONTENT: I, 4.8 PER CENT; II, 10.2 PER CENT; III, 15.2 PER CENT)

Section.	Water content.			Ratio of water content to hygroscopic coefficient.		
	Experiment I.	Experiment II.	Experiment III.	Experiment I.	Experiment II.	Experiment III.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1	18.0	19.6	20.8	1.8	2.0	2.1
2	16.5	17.5	20.1	1.6	1.7	2.0
3	13.0	15.4	19.2	1.3	1.5	1.9
Average, 1–3	15.8	17.5	20.0	1.6	1.7	2.0
4	6.5	10.2	18.1	.6	1.0	1.8

SOIL G (HYGROSCOPIC COEFFICIENT=8.2. INITIAL MOISTURE CONTENT: I, 3.9 PER CENT; II, 8.0 PER CENT; III, 12.4 PER CENT)

1	18.0	18.3	21.5	2.2	2.2	2.6
2	16.4	16.2	19.1	2.0	2.0	2.3
3	13.1	12.6	18.1	1.6	1.5	2.2
Average 1–3	15.8	15.7	19.6	1.9	1.9	2.4
4	5.9	8.5	14.6	.7	1.0	1.8

SOIL H (HYGROSCOPIC COEFFICIENT=7.6. INITIAL MOISTURE CONTENT: I, 3.8 PER CENT; II, 7.9 PER CENT; III, 11.2 PER CENT)

1	18.0	18.5	19.9	2.4	2.4	2.6
2	16.6	16.6	18.0	2.2	2.2	2.4
3	13.0	13.2	15.9	1.7	1.7	2.1
Average 1–3	15.9	16.1	17.9	2.1	2.1	2.4
4	5.3	7.9	12.1	.7	1.0	1.6

SOIL I (HYGROSCOPIC COEFFICIENT=7.1. INITIAL MOISTURE CONTENT: I, 3.5 PER CENT; II, 7.5 PER CENT; III, 10.4 PER CENT)

1	18.8	19.4	20.2	2.6	2.7	2.8
2	17.3	17.0	16.6	2.4	2.4	2.3
3	13.3	13.2	13.1	1.9	1.9	1.8
Average 1–3	16.5	16.5	16.6	2.3	2.3	2.3
4	4.9	7.1	10.4	.7	1.0	1.5

SOIL J (HYGROSCOPIC COEFFICIENT=5.6. INITIAL MOISTURE CONTENT: I, 2.8 PER CENT; II, 5.3 PER CENT; III, 8.3 PER CENT)

1	14.6	14.7	14.9	2.6	2.6	2.7
2	13.2	12.4	14.4	2.4	2.2	2.6
3	10.0	9.8	13.2	1.8	1.7	2.4
Average 1–3	12.6	12.3	14.2	2.3	2.2	2.6
4	4.1	5.6	11.2	.7	1.0	2.0

SOIL K (HYGROSCOPIC COEFFICIENT=3.4. INITIAL MOISTURE CONTENT: I, 1.7 PER CENT; II, 3.7 PER CENT; III, 4.8 PER CENT)

1	12.3	12.6	13.9	3.6	3.7	4.1
2	12.4	10.4	10.3	3.6	3.0	3.0
3	7.5	6.9	8.1	2.2	2.0	2.4
Average 1–3	10.7	10.0	10.8	3.1	2.9	3.2
4	2.7	3.7	4.8	.8	1.1	1.4

TABLE X.—*Distribution of moisture, and its relation to the hygroscopic coefficient 5 days after the application of 1 inch of water to the surface*—Continued

SOIL L (HYGROSCOPIC COEFFICIENT=3.4. INITIAL MOISTURE CONTENT: I, 1.6 PER CENT; II, 3.5 PER CENT; III, 5.0 PER CENT)

Section.	Water content.			Ratio of water content to hygroscopic coefficient.		
	Experiment I.	Experiment II.	Experiment III.	Experiment I.	Experiment II.	Experiment III.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1	10.5	10.0	9.9	3.1	2.9	2.9
2	8.7	8.8	10.3	2.6	2.6	3.0
3	6.3	6.6	9.7	1.9	1.9	2.9
Average 1–3	8.5	8.5	10.0	2.5	2.5	2.9
4	2.3	3.5	9.5	1.0	.7	2.8

SOIL M (HYGROSCOPIC COEFFICIENT=3.3. INITIAL MOISTURE CONTENT: I, 1.7 PER CENT; II, 3.7 PER CENT; III, 4.9 PER CENT)

1	14.1	14.5	13.3	4.3	4.4	4.0
2	12.6	12.0	10.6	3.8	3.6	3.2
3	9.1	9.0	8.3	2.7	2.7	2.5
Average 1–3	11.9	11.8	10.7	3.6	3.6	3.2
4	3.5	3.8	5.0	1.1	1.1	1.5

SOIL N (HYGROSCOPIC COEFFICIENT=1.7. INITIAL MOISTURE CONTENT: I, 0.6 PER CENT)

1	8.8	.....	.....	5.1	.....	.....
2	5.6	.....	.....	3.3	.....	.....
3	2.8	.....	.....	1.6	.....	.....
Average 1–3	5.7	.....	.....	3.3	.....	.....
4	1.6	.....	.....	.9	.....	.....

SOIL O (HYGROSCOPIC COEFFICIENT=1.1. INITIAL MOISTURE CONTENT: I, 0.4 PER CENT)

1	6.4	.....	.....	5.8	.....	.....
2	5.5	.....	.....	5.0	.....	.....
3	3.5	.....	.....	3.2	.....	.....
Average 1–3	5.1	.....	.....	4.7	.....	.....
4	.9	.....	.....	.8	.....	.....

SOIL P (HYGROSCOPIC COEFFICIENT=0.9. INITIAL MOISTURE CONTENT: I, 0.2 PER CENT)

1	5.9	.....	.....	6.5	.....	.....
2	6.0	.....	.....	6.7	.....	.....
3	3.3	.....	.....	3.7	.....	.....
Average 1–3	5.1	.....	.....	5.6	.....	.....
4	.5	.....	.....	.6	.....	.....

SOIL Q (HYGROSCOPIC COEFFICIENT=0.6)

1	9.0	.....	.....	15.0	.....	.....
2	8.2	.....	.....	13.7	.....	.....
3	3.7	.....	.....	6.2	.....	.....
Average 1–3	7.0	.....	.....	11.6	.....	.....
4	2.4	.....	.....	4.0	.....	.....

With soil Q the water did not advance evenly, but took a zigzag course, first on one side and then on the other. For this reason the data do not satisfactorily indicate the rate of movement of the water during the five days, and consequently the soil is not mentioned in those tables dealing with the rate.

RELATION OF APPARENT SPECIFIC GRAVITY TO MOISTNESS AND HYGROSCOPICITY

The weight of the moistened soil placed in each cylinder was determined, and from this and the capacity of the cylinders (1,730 c. c.) the weight of oven-dried soil and its apparent density have been calculated (Table XI). It will be seen that with any one soil the difference from experiment to experiment was small. With all the soils except I the density is lowest in the moistest form, and with all except J it is highest in the driest.

If we divide the soils into three groups according to texture, it will be seen that those in the intermediate group are intermediate also in apparent density, but when we compare the different members of each group there is no direct dependence of the relative density upon the hygroscopicity.

TABLE XI.—*Dry weight (in grams) of the soil contained in the different cylinders and its apparent specific gravity*

Soil.	Weight of dry soil.			Relative density.		
	Experiment I.	Experiment II.	Experiment III.	Experiment I.	Experiment II.	Experiment III.
A	2,207	2,050	1,994	1.28	1.18	1.15
B	2,106	2,048	1,969	1.22	1.18	1.14
C	2,106	2,015	1,920	1.22	1.16	1.11
D	2,080	1,982	1,910	1.20	1.14	1.10
E	2,160	2,004	1,940	1.25	1.16	1.12
F	2,380	2,160	2,066	1.37	1.25	1.19
G	2,237	2,153	1,967	1.29	1.24	1.14
H	2,211	2,075	1,975	1.28	1.20	1.14
I	2,164	1,950	2,054	1.25	1.13	1.19
J	2,316	2,341	2,147	1.34	1.35	1.24
K	2,508	2,488	2,354	1.45	1.44	1.36
L	2,706	2,547	2,497	1.57	1.47	1.44
M	2,508	2,460	2,445	1.45	1.42	1.42
N	2,741	.....	.....	1.58	.....	.....
O	2,951	.....	.....	1.70	.....	.....
P	2,716	.....	.....	1.57	.....	.....
Q	2,860	.....	.....	1.65	.....	.....

RELATION OF WATER RETENTIVENESS TO MAXIMUM WATER CAPACITY

A comparison of the maximum water capacity with the moisture content of the moistened layer at the end of the first hour will serve to show how little significance this value has as an expression of moisture retentiveness (Table XII). Even at the end of this short period, the moisture content is only from one-half to two-thirds this value, except in the case of soil B, which in a dry state delays the penetration of the water.

TABLE XII.—*Relation of the maximum water capacity of the soils to their moisture content at the end of the first hour*

Soil.	Maximum water capacity.	Water content of moistened layer at end of 1 hour.			Soil.	Maximum water capacity.	Water content of moistened layer at end of 1 hour.		
		Experiment I.	Experiment II.	Experiment III.			Experiment I.	Experiment II.	Experiment III
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
A.....	65.7	38.8	45.5	37.0	I.....	53.4	25.7	29.1	28.0
B.....	60.3	50.2	48.9	43.6	J.....	46.3	22.8	22.7	21.4
C.....	63.7	29.5	31.5	32.6	K.....	36.0	21.8	24.7	19.7
D.....	60.9	39.2	37.9	40.5	L.....	31.0	16.9	17.0	14.2
E.....	56.8	29.8	31.7	32.5	M.....	34.2	18.4	22.5	17.8
F.....	49.0	33.8	29.2	31.4	N.....	27.1	12.8	.....	.....
G.....	55.4	28.6	28.0	27.5	O.....	27.0	11.7	.....	.....
H.....	57.2	28.4	28.5	27.9	P.....	28.9	13.0	.....	.....

RAPIDITY OF CHANGE OF MOISTURE CONTENT IN THE MOISTENED LAYER

It is of interest to know the average moisture content of the moistened layer at the end of the successive intervals. This is reported in the second part of Table VIII, having been computed from the weight of dry soil in the cylinders, the initial moisture content, the weight of the added water, and the depth to which this had penetrated. These data assume much more significance when reported as the ratio of the moisture content to the hygroscopic coefficient as in the third part of the same table. In some of the finer-textured soils at the end of the first hour this ratio was as low as 3.0 to 3.2, while in some equally fine it was as high as from 3.7 to 4.1. In the fine sandy loams it had not fallen below 4.2 to 7.2 at the end of the hour, while in the sands it was as high as 7.5 to 14.8. The fall in the ratio after the first hour was so rapid that at the end of the first day it was between 2.0 and 3.0 in the case of the soils with a hygroscopic coefficient above 5.5, and was between 2.9 and 5.0 for the group of soils with a coefficient of about 3.3. In all, however, even in the coarsest soils, the decline was marked. During the following four days the decline was slight, being greatest in the sands, as shown in Table XIII.

TABLE XIII.—*Change in the moistened layer of the ratio of the water content to the hygroscopic coefficient and the proportion of the total distance of penetration covered during successive intervals following the application of 1 inch of water to the surface of the soil columns*

SOIL A (HYGROSCOPIC COEFFICIENT=13.3)

Interval.	Fall in ratio of water content to hygroscopic coefficient.			Proportion of total distance of penetration covered during interval.		
	Experiment I.	Experiment II.	Experiment III.	Experiment I.	Experiment II.	Experiment III
				Per ct.	*Per ct.*	*Per ct.*
First hour	.....	.....	.....	59.8	37.6	43.6
First to third hour	0.5	1.1	0.4	15.6	32.2	21.2
Third to twenty-fourth hour	.4	.3	.3	19.6	19.5	22.1
Second day	.1	.0	.0	5.0	5.0	4.6
Third day	.....	.1	.0	.....	2.4	4.4
Fourth day	.....	.0	.0	.....	.3	2.4
Fifth day	.....	.1	.0	.....	3.0	1.7

SOIL B (HYGROSCOPIC COEFFICIENT=12.9)

First hour	.....	.....	.....	39.8	30.3	48.7
First to third hour	1.2	1.1	0.6	21.9	21.5	27.3
Third to twenty-fourth hour	.6	.7	.3	24.7	31.7	24.1
Second day	.1	.1	.....	4.1	8.8	.....
Third day	.1	.0	.....	4.3	4.1	.....
Fourth day	.1	.0	.....	5.2	1.6	.....
Fifth day	.0	.1	.....	.....	2.1	.....

SOIL C (HYGROSCOPIC COEFFICIENT=10.5)

First hour	.....	.....	.....	69.0	58.8	51.3
First to third hour	0.3	0.5	0.4	8.1	10.3	11.5
Third to twenty-fourth hour	.3	.1	.2	13.9	18.0	21.1
Second day	.0	.1	.1	2.9	5.7	7.2
Third day	.1	.0	.0	6.1	3.8	3.5
Fourth day	.....	.1	.1	.....	2.3	3.0
Fifth day	.....	.0	.0	.....	1.1	3.4

SOIL D (HYGROSCOPIC COEFFICIENT =10.2)

First hour	.....	.....	.....	57.0	48.8	40.9
First to third hour	0.6	0.7	0.8	12.1	17.5	19.4
Third to twenty-fourth hour	.6	.4	.5	23.5	19.4	23.5
Second day	.2	.2	.1	5.3	6.8	4.4
Third day	.0	.0	.0	2.1	2.5	4.5
Fourth day	.....	.0	.0	.....	2.5	3.2
Fifth day	.....	.1	.1	.....	2.5	4.1

TABLE XIII.—*Change in the moistened layer of the ratio of the water content to the hygroscopic coefficient and the proportion of the total distance of penetration covered during successive intervals following the application of 1 inch of water to the surface of the soil columns*—Continued

SOIL E (HYGROSCOPIC COEFFICIENT=10.1)

Interval.	Fall in ratio of water content to hygroscopic coefficient.			Proportion of total distance of penetration covered during interval.		
	Experiment I.	Experiment II.	Experiment III.	Experiment I.	Experiment II.	Experiment III.
				Per ct.	*Per ct.*	*Per ct.*
First hour	.....	.....	.....	63.0	47.4	50.6
First to third hour	0.2	0.5	0.4	7.0	14.2	18.2
Third to twenty-fourth hour	.5	.3	.3	19.0	19.1	19.4
Second day	.1	.1	.0	7.0	7.2	4.3
Third day	.0	.1	.1	3.2	4.9	3.6
Fourth day	.0	.0	.0	.8	4.3	2.3
Fifth day	.0	.1	.0	.....	2.9	1.6

SOIL F (HYGROSCOPIC COEFFICIENT=10.0)

First hour	.....	.....	.....	49.6	48.3	58.1
First to third hour	0.6	0.4	0.5	12.6	13.2	28.5
Third to twenty-fourth hour	.6	.4	.1	25.2	21.3	13.4
Second day	.1	.1	.....	4.0	7.2	.....
Third day	.1	.0	.....	8.6	4.1	.....
Fourth day	.....	.0	.....	.....	2.8	.....
Fifth day	.....	.1	.....	.....	3.1	.....

SOIL G (HYGROSCOPIC COEFFICIENT=8.2)

First hour	.....	.....	.....	55.3	48.2	57.2
First to third hour	0.4	0.4	0.4	8.3	10.6	12.8
Third to twenty-fourth hour	.7	.6	.3	20.9	20.2	19.2
Second day	.1	.1	.0	7.1	9.0	3.1
Third day	.1	.1	.1	4.1	4.9	3.7
Fourth day	.1	.0	.0	4.3	4.2	1.9
Fifth day	.....	.0	.0	.....	2.9	2.1

SOIL H (HYGROSCOPIC COEFFICIENT=7.6)

First hour	.....	.....	.....	56.3	48.6	51.3
First to third hour	0.2	0.6	0.6	5.0	10.6	12.0
Third to twenty-fourth hour	.8	.5	.3	23.8	21.0	23.3
Second day	.2	.2	.1	6.5	7.6	5.8
Third day	.1	.0	.1	4.1	4.3	3.8
Fourth day	.1	.1	.0	4.3	4.7	1.9
Fifth day	.....	.0	.1	.....	2.9	1.9

TABLE XIII.—*Change in the moistened layer of the ratio of the water content to the hygroscopic coefficient and the proportion of the total distance of penetration covered during successive intervals following the application of 1 inch of water to the surface of the soil columns*—Continued

SOIL I (HYGROSCOPIC COEFFICIENT=7.1)

Interval.	Fall in ratio of water content to hydroscopic coefficient.			Proportion of total distance of penetration covered during interval.		
	Experiment I.	Experiment II.	Experiment III.	Experiment I.	Experiment II.	Experiment III.
				Per ct.	*Per ct.*	*Per ct.*
First hour	.....	.....	.....	70.9	54.9	52.0
First to third hour	0.2	0.5	0.4	4.8	10.5	11.8
Third to twenty-fourth hour	.4	.6	.5	13.3	18.6	22.5
Second day	.2	.1	.1	7.8	6.9	5.2
Third day	.1	.1	.1	3.2	3.8	4.3
Fourth day	.....	.0	.0	.....	1.1	2.6
Fifth day	.....	.1	.1	.....	4.2	1.6

SOIL J (HYGROSCOPIC COEFFICIENT=5.6)

First hour	.....	.....	.....	56.0	48.2	50.6
First to third hour	0.4	0.5	0.4	5.8	9.9	10.5
Third to twenty-fourth hour	.8	.5	.5	21.4	18.9	24.6
Second day	.2	.2	.1	4.8	8.1	6.7
Third day	.0	.1	.1	4.1	5.8	3.6
Fourth day	.1	.1	.0	4.8	5.4	2.0
Fifth day	.1	.1	.0	3.1	3.7	2.0

SOIL K (HYGROSCOPIC COEFFICIENT=3.4)

First hour	.....	.....	.....	55.0	37.6	48.8
First to third hour	0.4	1.9	1.0	3.0	15.4	14.2
Third to twenty-fourth hour	1.4	1.3	.9	20.4	23.5	20.4
Second day	.3	.3	.1	8.2	8.9	6.8
Third day	.3	.2	.2	5.8	5.7	5.1
Fourth day	.1	.1	.0	3.7	4.4	2.7
Fifth day	.2	.1	.0	3.9	4.5	2.0

SOIL L (HYGROSCOPIC COEFFICIENT=3.4)

First hour	.....	.....	.....	52.9	42.5	53.7
First to third hour	0.5	0.9	0.6	6.5	13.2	15.2
Third to twenty-fourth hour	1.3	1.0	.7	26.8	24.2	31.1
Second day	.1	.1	.....	6.0	7.4	.....
Third day	.1	.0	.....	2.6	1.6	.....
Fourth day	.1	.2	.....	3.1	7.8	.....
Fifth day	.0	.1	.....	2.1	3.3	.....

TABLE XIII.—*Change in the moistened layer of the ratio of the water content to the hygroscopic coefficient and the proportion of the total distance of penetration covered during successive intervals following the application of 1 inch of water to the surface of the soil columns*—Continued

SOIL M (HYGROSCOPIC COEFFICIENT=3.3)

Interval.	Fall in ratio of water content to hygroscopic coefficient.			Proportion of total distance of penetration covered during interval.		
	Experiment I.	Experiment II.	Experiment III.	Experiment I.	Experiment II.	Experiment III.
				Per ct.	*Per ct.*	*Per ct.*
First hour	.....	.....	.....	72.0	49.2	52.5
First to third hour	0.3	1.6	0.8	4.2	20.0	12.6
Third to twenty-fourth hour	.7	.9	.7	13.3	18.2	19.4
Second day	.1	.2	.2	4.3	4.7	7.2
Third day	.1	.0	.1	1.9	3.1	4.2
Fourth day	.2	.1	.0	4.3	2.7	2.3
Fifth day	.....	.1	.1	.....	2.1	1.8

SOIL N (HYGROSCOPIC COEFFICIENT=1.7)

First hour	.....	.....	.....	58.3	.....	.....
First to third hour	0.6	.....	.....	4.3	.....	.....
Third to twenty-fourth hour	1.4	.....	.....	15.7	.....	.....
Second day	.5	.....	.....	7.2	.....	.....
Third day	.3	.....	.....	6.6	.....	.....
Fourth day	.2	.....	.....	4.3	.....	.....
Fifth day	.2	.....	.....	3.5	.....	.....

SOIL O (HYGROSCOPIC COEFFICIENT=1.1)

First hour	.....	.....	.....	49.7	.....	.....
First to third hour	1.6	.....	.....	9.5	.....	.....
Third to twenty-fourth hour	2.4	.....	.....	21.8	.....	.....
Second day	.3	.....	.....	7.1	.....	.....
Third day	.3	.....	.....	5.1	.....	.....
Fourth day	.1	.....	.....	3.8	.....	.....
Fifth day	.3	.....	.....	3.0	.....	.....

SOIL P (HYGROSCOPIC COEFFICIENT=0.9)

First hour	.....	.....	.....	50.0	.....	.....
First to third hour	2.2	.....	.....	8.8	.....	.....
Third to twenty-fourth hour	1.4	.....	.....	9.5	.....	.....
Second day	1.4	.....	.....	10.5	.....	.....
Third day	1.0	.....	.....	11.2	.....	.....
Fourth day	.4	.....	.....	4.4	.....	.....
Fifth day	.7	.....	.....	5.6	.....	.....

RELATION OF THE RAPIDITY WITH WHICH EQUILIBRIUM IS ATTAINED TO THE HYGROSCOPICITY

That at the end of the five days equilibrium had been practically attained in the case of the finer-textured soils, H to G, may be seen from Table XIV, in which the ratios in the upper layers of the moistened portion of the columns in this experiment are compared with that in similar layers of the same soils in an earlier experiment (2, p. 50) in which, after the addition of water to the surface, the columns had been left undisturbed for much longer periods, 66 to 110 days. In the case of the coarser members, as the fine sandy loams K, L, and M, equilibrium was far from having been reached at the end of five days, the ratio being as much as 1.2 to 1.7 higher than when the exposure was for the longer period. With the coarse sands the fall is still greater (2, p. 57). The coarser the soil the greater will be the fall in the ratio after the fifth day. In the earlier experiment the soils were used in only the one degree of moistness.

TABLE XIV.—*Extent to which equilibrium had been attained by the different soils at the end of five days, as shown by comparing the ratios of water content to hygroscopic coefficient in the first and second 3-inch sections in the present experiment (I) with those found in an earlier one (II) in which the exposure had been much longer*

Soil.	Hygroscopic coefficient.	Experiment No.	Initial ratio.	Amount water added.	Time of exposure.	Ratio at end of experiment.		Fall in ratio after fifth day.	
						1 to 3-inch section.	4 to 6-inch section.	1 to 3-inch section.	4 to 6-inch section.
				Inches.	*Days.*				
A	13.3	I	1.0	1.00	5	1.9	1.7	0.0	0.0
		II	1.0	2.11	110	2.0	1.8	.....	.....
B	12.9	I	1.0	1.00	5	1.8	1.6	.0	.0
		II	1.0	2.12	69	1.9	1.8	.....	.....
C	10.5	I	1.1	1.00	5	2.2	1.9	.1	.0
		II	1.1	1.21	100	2.1	1.9	.....	.....
D	10.2	I	1.0	1.00	5	2.4	1.9	.2	.0
		II	1.3	.90	110	2.2	2.0	.....	.....
E	10.1	I	1.0	1.00	5	2.1	2.0	.2	.2
		II	1.0	1.42	100	1.9	1.8	.....	.....
G	8.2	I	1.0	1.00	5	2.2	2.0	.2	.0
		II	1.0	1.58	106	2.0	2.0	.....	.....
H	7.6	I	1.0	1.00	5	2.4	2.2	.1	.1
		II	1.2	1.28	102	2.3	2.1	.....	.....
I	7.1	I	1.1	1.00	5	2.3	1.9	.2	.0
		II	1.2	.60	102	2.1	1.9	.....	.....
J	5.6	I	1.0	1.00	5	2.6	2.2	.5	.3
		II	1.0	.89	70	2.1	1.9	.....	.....
K	3.4	I	1.1	1.00	5	3.7	3.0	1.5	1.1
		II	1.3	.33	100	2.2	1.9	.....	.....
L	3.4	I	1.0	1.00	5	2.9	2.7	1.2	1.1
		II	1.3	.27	68	1.7	1.6	.....	.....
M	3.3	I	1.1	1.00	5	4.1	3.0	1.7	1.0
		II	1.3	.35	100	2.4	2.0	.....	.....

RELATION OF RATE OF PENETRATION TO THE HYGROSCOPICITY

The distance of penetration shows surprisingly little dependence upon the texture as expressed by either the hygroscopic coefficient or the moisture equivalent (Table XV). Thus, soils E, H, and M, with coefficients of 10.1, 7.6, and 3.3, respectively, in Experiments II and III show a penetration almost identical both at the end of 24 hours and at the end of 5 days, and in Experiment I the differences are very slight (Table XVI). It was to be expected that the rate of movement would vary inversely as the fineness of texture of the soils. The nearest approach to such a relation is exhibited when the soils are used in the driest form, and at the end of the fifth day it is more evident than during the first 24 hours.

TABLE XV.—*Distances to which 1 inch of water had penetrated at the end of 24 hours and 5 days, respectively, showing the relation to the hygroscopic coefficient and to the moisture equivalent*

Soil.	Hygroscopic coefficient.	Moisture equivalent.	Distance of penetration.					
			At end of 24 hours.			At end of 5 days.		
			Experiment I.	Experiment II.	Experiment III.	Experiment I.	Experiment II.	Experiment III.
			Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
A	13.3	29.5	3.8	6.2	10.1	3.9	6.9	11.7
B	12.9	25.8	4.0	6.3	.....	4.6	7.6	.....
C	10.5	24.1	4.4	6.1	8.6	4.8	7.0	10.3
D	10.2	27.8	3.9	5.4	7.4	4.2	6.3	8.9
E	10.1	22.5	4.4	6.6	8.8	5.0	8.2	10.0
F	10.0	19.2	4.4	7.2	.....	5.0	8.7	.....
G	8.2	21.2	4.8	6.5	8.8	5.6	8.2	9.8
H	7.6	19.7	4.8	6.6	8.8	5.6	8.3	10.2
I	7.1	16.8	4.5	6.2	7.8	5.0	7.4	9.1
J	5.6	13.5	5.5	6.7	10.3	6.6	8.7	12.0
K	3.4	7.5	4.8	6.8	8.3	6.2	8.9	10.0
L	3.4	7.2	6.7	9.3	[a] 13.8	7.8	11.7	.....
M	3.3	7.9	5.0	6.6	8.7	5.6	7.5	10.3
N	1.7	3.0	6.8	.....	.....	8.8	.....	.....
O	1.1	2.8	8.3	.....	.....	10.3	.....	.....
P	.9	1.6	6.7	.....	.....	9.8	.....	.....

[a] At the bottom of the cylinders.

TABLE XVI.—*Lack of dependence of depth of penetration upon the texture when 1 inch of water is applied, as illustrated by three dissimilar soils*

Soil.	Hygroscopic coefficient.	Moisture equivalent.	Depth of penetration.					
			In 24 hours.			In 5 days.		
			Experiment I.	Experiment II.	Experiment III.	Experiment I.	Experiment II.	Experiment III.
			Inches.	*Inches.*	*Inches.*	*Inches.*	*Inches.*	*Inches.*
E	10.1	22.5	4.4	6.6	8.8	5.0	8.2	10.0
H	7.6	19.7	4.8	6.6	8.8	5.6	8.3	10.2
M	3.3	7.9	5.0	6.6	8.7	5.6	7.5	10.3

RELATION OF RATE OF PENETRATION TO INITIAL MOISTNESS

The influence of the initial moisture content upon the rate of penetration of the water may be seen from Table VIII. In the case of all the soils at the end of the first hour the water had penetrated farthest in the moistest form of the soil, and, except with soils K and M, the shortest distance in the driest form; in soil K the penetration was practically the same in the driest as in the intermediate condition, while with M it was least when in the latter moisture condition.

At the end of the third hour and each subsequent interval in the case of every soil, including K and M, the penetration was greatest with the soil in the most moist form and least with that in the driest.

However, in most of the cylinders equilibrium had not yet set in at the end of the fifth day after the addition of the water. Where the driest forms (Experiment I) were used, appreciable movement appeared to have ceased with the finest textured soils at the end of the third or fourth day, but this was not the case with the moister forms. This lack of dependence of the distance of movement upon the hygroscopicity holds even after long periods, as may be seen from the data on soils A, B, L, and M in the earlier experiments (2, p. 49).

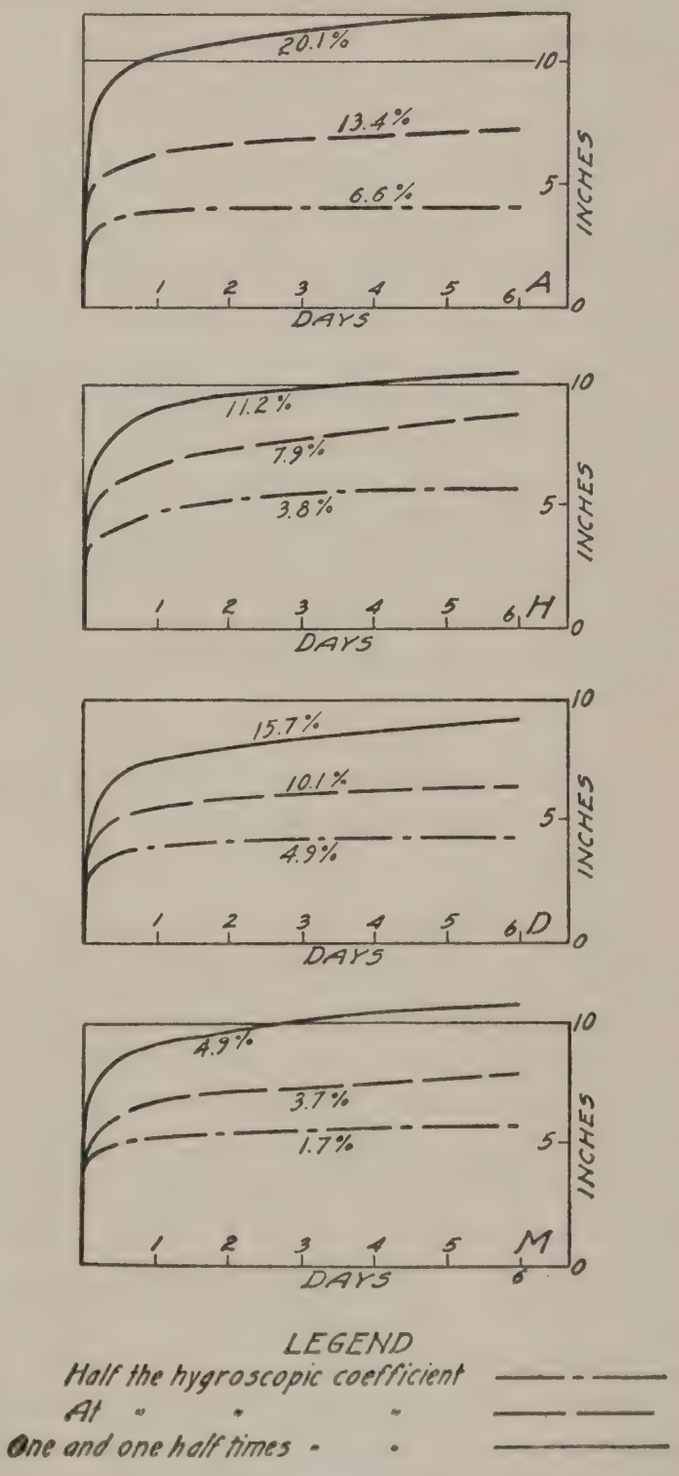

FIG. 1.—Graphs showing the penetration of 1 inch of water in soils A, D, H, and M, each in three moisture conditions—viz, with a moisture content of 0.5, 1.0, and 1.5 times the hygroscopic coefficient.

The rate of downward movement in soils A, D, H, and M is shown graphically in figure 1. These well illustrate the movement in all those soils with hygroscopic coefficients above 3.0. With each there was at

first a very rapid rise, after which the movement rapidly slackened until it became almost or quite imperceptible; the higher the initial moisture content the more gradual was the transition from the rapid to the slow movement. The early rapid movement might be regarded as being due chiefly to gravity and the later slow movement entirely to capillarity.

RELATION OF WATER CONTENT OF MOISTENED LAYER TO INITIAL MOISTNESS

Table VIII shows that the initial moisture content has no distinct effect upon the moisture content at the end of the first hour, the maximum being shown by three of the soils when driest and by four of them when in the moistest condition. Even at the end of the third hour, there is no regularity to be observed except with the coarser members of the series, J to M, in which the moisture content varies inversely as the initial moisture content, the higher rate of penetration in the moister forms being more than sufficient to compensate for the differences in the initial moisture content. After 24 hours the same is to be observed. At the end of the five days the differences with these coarser members are of the same character but much smaller, while the finer-textured soils show the highest moisture content in those cylinders filled with the moistest form of the soils.

RELATION OF LOSS OF MOISTURE DURING DRY WEATHER FOLLOWING A RAIN TO THE HYGROSCOPICITY OF THE SOIL AND ITS MOISTNESS BEFORE THE RAIN

From the above it would appear that the character of the weather immediately following a rain would determine the loss of moisture from the surface soil much more in the case of a sandy soil than in one of finer texture. In the coarser soils, on account of the tardiness with which equilibrium is reached in the immediate surface layer and the greater possible distance of penetration, a period of low evaporation (of low temperature, cloudy skies, high atmospheric humidity, slight wind movement) following a rain of an inch or less will be more markedly beneficial, provided that a period of high evaporation is to occur before the next rain, and that in the interval there are no plants present to make use of the moisture of the surface soil.

Under similar assumed subsequent weather conditions the ultimate effect of a lower initial moistness of the surface layers will be a greater loss of water through direct evaporation on account of the lesser depth of penetration and the equal or even higher water content in the immediate surface layers.

UPWARD MOVEMENT IN SOILS DIFFERING IN INITIAL MOISTURE CONTENT [1]

EXPERIMENTS

The same soils were employed as in the experiments described above, using parts of the same three preparations of each, carrying approximately 0.5, 1.0, and 1.5 times the hygroscopic coefficient, placed in glass tubes of an inside diameter of 3.0 cm. and 160 cm. long. The glass was of poor quality, and many of the tubes cracked during the experiments, thus with some interrupting the observations and with others preventing any being made.

In the first and second experiments, those in which the soil moisture was 0.5 and 1.0 times the hygroscopic coefficient, because of the difficulty of satisfactorily tamping the soil into so narrow a tube, the tubes were filled by jarring. In filling a tube the end, covered by fine copper gauze, was first rested upon a large rubber stopper on the cement floor. It was held in position by one operator, who raised it about 6 inches above the stopper and brought it down upon this in a succession of smart blows, while another operator added the soil in a slow stream through a funnel. As the soils in the third experiment were too moist to permit the tubes to be conveniently filled in this manner, the tubes were connected with a metal funnel of the same diameter as the tube by means of rubber hose, and a small tamper, consisting of a one-hole rubber stopper on a wooden rod, was operated through the funnel and kept in constant motion, striking sharp, uniform blows while a slow stream of soil was added.

After all the tubes had been filled, they were placed upright in a rack, the lower end of each dipping into a metal trough and resting on a strip of 0.25-inch mesh wire screen, the object of which was to facilitate both the entrance of water and the escape of air. Throughout the experiments the water in the trough was maintained at a depth of 1.5 inches. In the first two the tubes were allowed to remain in contact with the water for 10 days, and in the third 8. The height of rise was observed at the end of 1, 2, 3, 4, and 24 hour intervals during the first day, and after that at the end of each 24-hour period (Table XIX). The readings actually made were to 1 mm. but to facilitate comparison they are reported only in even centimeters, the difference being negligible in comparison with the differences between duplicates.

INFLUENCE UPON THE RISE OF METHOD OF COMPACTING SOIL

On comparing the results obtained in the second experiment with those in the third, we suspected that there might have been some disturbing factor introduced by the different methods employed in filling the tubes. As a supply of two of the moistened soils, D and H, surface

[1] Mr. Jouette C. Russell assisted in this part of the work.

soil and subsoil, respectively, had been saved from the previous experiments and kept in tightly sealed jars and so were in the same moisture conditions as when previously employed, we filled two tubes with each, one by jarring and the other by tamping as above described. These six pairs of tubes we allowed to remain in contact with the water for 10 days, as in Experiments I and II, the rate of rise being observed as before and reported in Table XVII in the column headed "Later experiment."

TABLE XVII.—*Concordance of data as affected by method of filling tubes and by parallelism of experiments*

SOIL H (HYGROSCOPIC COEFFICIENT=7.6)

Time.	Experiment I. (Moisture content=0.5 hygroscopic coefficient.)				Experiment II. (Moisture content=1.0 hygroscopic coefficient.				Experiment III. (Moisture content=1.5 hygroscopic coefficient.			
	From Table XVIII.		Later experiment.		From Table XVIII.		Later experiment.		From Table XVIII.		Later experiment.	
	Tube 1, jarred.	Tube 2, jarred.	Tube 1, jarred.	Tube 2, tamped.	Tube 1, jarred.	Tube 2, jarred.	Tube 1, jarred.	Tube 2, tamped.	Tube 1, tamped.	Tube 2, tamped.	Tube 1, tamped.	Tube 2, jarred.
Hr.	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*
1.....	18	18	18	17	19	18	19	16	20	20	21	18
2.....	25	25	24	23	27	23	27	23	28	27	31	25
3.....	30	30	31	31	32	28	33	28	33	33	38	29
4.....	34	33	32	32	36	(a)	37	32	38	38	42	33
24....	72	72	68	69	63	.....	77	72	78	79	79	72
48....	95	93	90	90	80	.....	96	95	100	104	.....	.....
72....	108	107	104	105	87	.....	.....	.....	115	118	.....	.....
96....	119	118	114	115	91	.....	.....	.....	126	(b)	.....	.....
120...	127	126	122	124	94	.....	.....	.....	133	.....	.....	.....
144...	135	134	128	132	95	.....	.....	.....	140	.....	.....	.....
168...	140	139	133	138	97	.....	.....	.....	146	.....	.....	.....
192...	144	144	.....	.....	98	.....	.....	.....	150	.....	.....	.....
216...	149	148	.....	.....	99	.....	.....	.....	.....	.....	.....	.....
240...	151	151	.....	.....	100	.....	.....	.....	.....	.....	.....	.....

SOIL D (HYGROSCOPIC COEFFICIENT=10.2)

1.....	8	8	7	7	10	11	10	8	9	12	11	8
2.....	11	11	10	10	15	16	13	11	12	16	14	10
3.....	13	13	12	12	18	18	16	14	15	19	16	13
4.....	15	15	13	13	20	21	18	16	18	22	18	15
24....	32	33	31	31	40	39	36	33	36	41	31	32
48....	41	43	41	40	49	48	43	42	46	51	36	42
72....	46	48	46	45	55	54	48	48	55	57	41	48
96....	50	52	50	49	60	58	52	52	57	62	45	53
120...	53	56	54	52	63	62	54	56	61	66	47	57
144...	55	58	57	54	66	64	57	58	63	69	49	60
168...	57	61	59	57	69	67	59	61	65	72	52	63
192...	59	63	61	58	71	69	61	63	67	74	54	65
216...	61	64	.....	.....	72	71	63	65	.....	.....	56	68
240...	62	66	.....	.....	74	72	64	67	.....	.....	57	70

[a] The soil column broke at end of third hour. [b] Tube cracked.

With the soils in the driest condition no influence of the tamping versus the jarring is shown, while in the moistest both showed a slower rise during the first 24 hours when tamped, but the one a somewhat more rapid rise during the following nine days, the tube with the other breaking before the end of the second day. In the intermediate condition both soils at first showed the more rapid rise in the tube filled by jarring, but

here also the movement in the other tube later became as rapid. The table includes the data on these two soils, later averaged in Table XVIII to show the influence of parallelism of experiment. The concordance of the data on the rise in a soil appears to depend more upon the exposure of the two tubes at the same time than upon the compacting of the soil in the same manner. In general the divergence was greatest when the soils were used in the most moist condition. However, on the whole, the data would appear to justify the comparison of the data from the third experiment with those from the first and second.

TABLE XVIII.—*Rise in tubes of soil with the lower end immersed in water kept at a constant level. In the three experiments, I, II, and III, the initial moisture content of the soil mass was, respectively, 0.5, 1.0, and 1.5 times the hygroscopic coefficient. The data are arranged so as to show the relation of the rate of rise to the initial moisture content*

Time.	Soil A.			Soil B.			Soil C.		
	Experiment I.	Experiment II.	Experiment III.	Experiment I.	Experiment II.	Experiment III.	Experiment I.	Experiment II.	Experiment III.
Hours.	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*
1	6	14	18	5	10	16	12	18	17
2	8	20	23	8	14	20	16	24	23
3	10	24	26	9	17	23	20	28	27
4	12	27	29	10	19	25	22	30	30
24	33	50	51	26	35	38	48	51	53
48	50	60	62	36	43	.....	62	60	64
72	60	67	69	41	49	.....	70	65	70
96	68	73	74	46	53	.....	75	70	75
120	74	77	79	49	56	.....	79	73	79
144	81	81	83	53	59	.....	82	76	83
168	87	84	86	56	61	.....	85	78	85
192	92	87	89	58	63	.....	89	80	87
216	97	90	.....	60	64	.....	90	82	.....
240	100	92	.....	62	66	.....	92	84	.....
	Soil D.			Soil E.			Soil F.		
1	8	10	10	12	17	18	7	18	18
2	11	15	14	17	25	25	11	23	23
3	13	18	17	21	29	30	13	26	26
4	15	20	20	23	31	34	14	29	29
24	32	39	38	53	54	65	35	43	47
48	42	48	48	69	65	80	46	51	58
72	47	54	56	78	71	90	52	55	.....
96	51	59	59	86	76	.....	58	59	.....
120	54	62	63	92	80	.....	62	62	.....
144	56	65	66	96	83	.....	65	64	.....
168	59	68	68	101	86	.....	69	66	.....
192	61	70	70	105	88	.....	72	69	.....
216	62	71	.....	108	90	.....	74	70	.....
240	64	73	.....	111	92	.....	76	72	.....
	Soil G.			Soil H.			Soil I.		
1	12	15	19	18	18	20	21	18	16
2	17	22	26	25	25	27	28	23	21
3	20	.....	31	30	30	33	32	27	24
4	23	32	36	33	.....	38	35	.....	28
24	53	46	73	72	60	78	59	44	48
48	70	63	95	94	78	102	68	51	57
72	81	74	109	107	87	116	71	54	62
96	91	83	119	118	93	.....	73	57	66
120	99	89	128	126	99	.....	75	59	69
144	104	93	134	134	102	.....	76	61	71
168	111	98	140	139	104	.....	76	62	73
192	115	101	145	144	108	.....	77	62	74
216	120	104	.....	148	110	.....	78	63	.....
240	124	108	.....	151	112	.....	79	64	.....

TABLE XVIII.—*Rise in tubes of soil with the lower end immersed in water kept at a constant level, etc.*—Continued.

Time.	Soil J.			Soil K.			Soil L.			Soil M.		
	Experiment I.	Experiment II.	Experiment III.	Experiment I.	Experiment II.	Experiment III.	Experiment I.	Experiment II.	Experiment III.	Experiment I.	Experiment II.	Experiment III.
Hours.	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*
1	18	20	24	32	31	33	28	34	29	26	20	22
2	24	27	32	42	40	43	35	41	36	31	25	27
3	27	32	38	48	46	49	40	46	39	34	27	30
4	30	35	43	52	50	54	43	50	42	36	29	33
24	58	62	78	82	71	80	64	72	56	47	38	49
48	72	73	94	90	78	88	69	80	61	51	41	55
72	80	79	104	93	82	93	72	83	64	53	42	58
96	85	84	111	95	85	96	73	.....	67	53	43	60
120	89	88	116	97	87	98	74	.....	69	54	44	62
144	92	90	121	99	89	100	76	.....	70	54	45	64
168	95	93	125	100	90	102	77	.....	72	55	45	65
192	97	95	128	101	91	103	78	.....	73	55	46	65
216	99	97	.....	102	92	.....	79	.....	74	56	46	.....
240	101	98	.....	103	93	.....	80	.....	75	56	47	.....

The data in Table XVII in the columns headed "From Table XVIII" serve to illustrate the concordance of data from the duplicates, the averages only of which are reported in Table XVIII. Only with soils D, F, G, and J in Experiment I and with soils F, G, and H in Experiment II does the divergence approach in magnitude that shown in Table XVII by D in the driest condition.

RELATION OF RISE TO HYGROSCOPICITY

In Table XIX the data are rearranged to show what relation the rapidity and distance of rise bear to the hygroscopicity in each of the three moisture conditions. At first the coarser soils showed the most rapid rise, but the difference gradually lessened until those of intermediate hygroscopicity led. After the first three or four days the two subsoils G and H, with coefficients of 8.2 and 7.6, respectively, showed the most rapid rise in all three moisture conditions. Closely following these was the subsoil K, with a coefficient of 3.4, while L, with a coefficient also of 3.4, was still farther behind. This difference among the three soils, alike in hygroscopicity, was shown in all three moisture conditions. Soils A, J and K, differing widely in hygroscopicity, 13.3, 5.6, and 3.4, respectively, were much alike at the end of 10 days in Experiments I and II, but differed much in Experiment III. In soil B, and to a less extent in D, with coefficients of 12.9 and 10.2, respectively, the rise was very slow in all three experiments. There thus appears no definite dependence of the rate of rise upon the hygroscopicity (fig. 2).

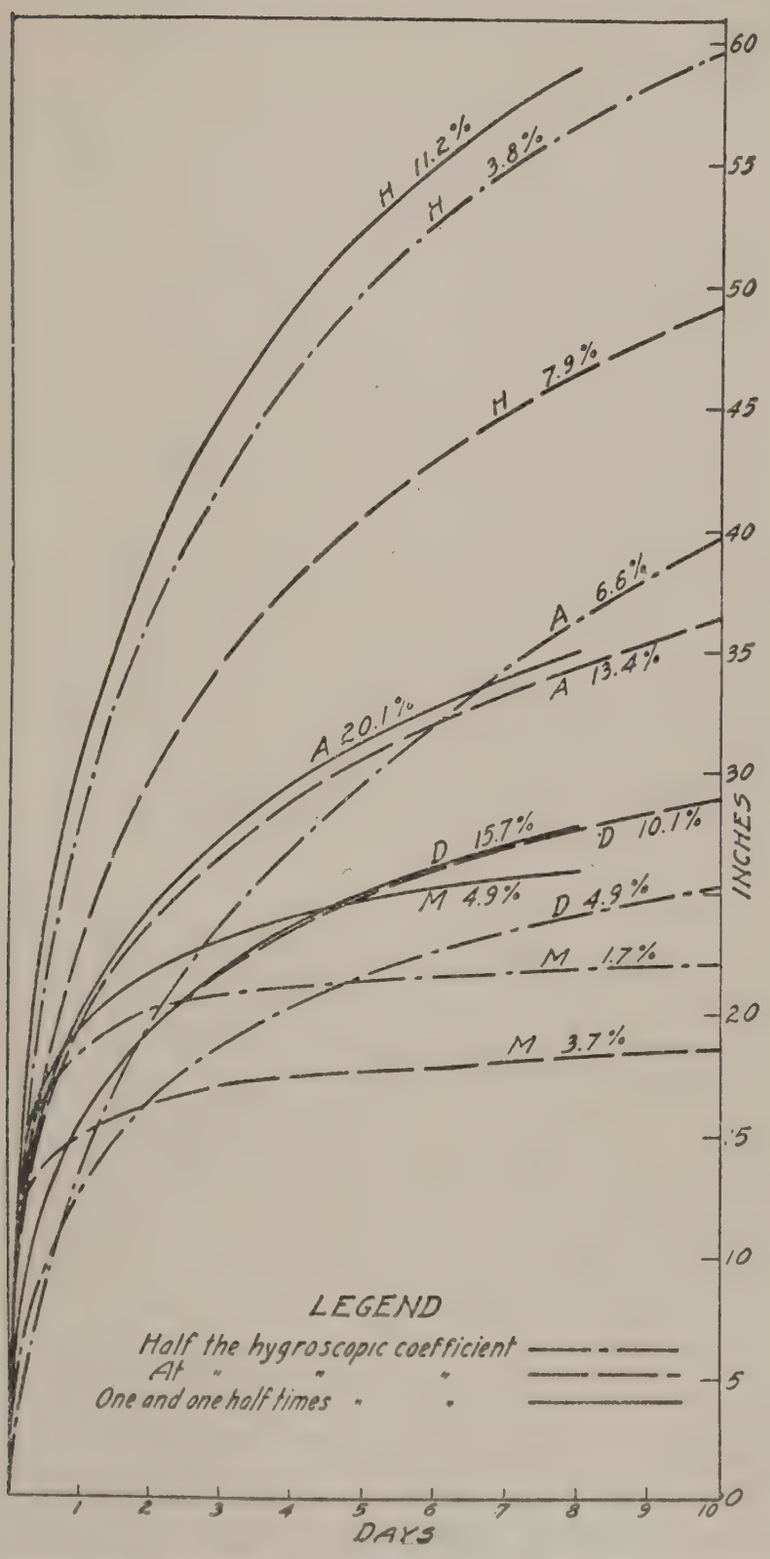

FIG. 2.—Graphs showing the rise of water in soils A, D, H, and M, each in three moisture conditions, viz., with a moisture content of 0.5, 1.0, and 1.5 times the hygroscopic coefficient.

TABLE XIX.—*Data from Table XVIII rearranged to show relation of rate of rise to the hygroscopicity of the soils*

EXPERIMENT I (MOISTURE CONTENT=0.5 HYGROSCOPIC COEFFICIENT)

Time.	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
Hours.	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*	*Cm.*
1	6	6	12	8	12	8	13	18	21	18	33	28	26	35	21	34	20
2	9	8	16	11	17	11	17	25	27	24	42	35	32	41	27	39	22
3	11	9	20	14	21	13	21	30	31	28	48	40	34	44	30	42	24
4	12	11	23	15	23	15	23	34	35	31	52	43	36	45	33	43	25
24	33	26	48	32	53	35	53	72	59	58	82	65	47	57	51	48	30
48	50	36	62	42	69	46	70	94	68	72	90	69	51	60	58	50	31
72	60	41	70	47	79	53	82	107	71	80	93	72	53	62	62	52	31
96	68	46	75	51	86	58	91	118	73	86	96	73	53	64	.....	54	31
120	75	50	80	54	92	62	99	127	75	89	97	75	54	65	.....	55	31
144	81	53	83	57	97	66	105	134	76	93	99	76	55	66	.....	57	31
168	87	56	86	59	101	69	111	139	77	95	100	77	55	66	.....	58	31
192	92	58	89	61	105	72	116	144	78	98	101	79	56	67	.....	59	31
216	97	61	91	63	109	74	121	148	79	100	103	80	56	.....	.....	.....	.....
240	101	63	93	64	111	76	125	151	79	101	103	81	56	.....	.....	.....	.....

EXPERIMENT II (MOISTURE CONTENT=1.0 HYGROSCOPIC COEFFICIENT)

1	14	10	18	11	18	18	15	18	18	20	31	29	21	.....	.....	.....	.....
2	20	14	24	15	24	23	22	25	24	27	41	36	25	.....	.....	.....	.....
3	24	17	28	18	28	27	26	30	27	32	46	39	27	.....	.....	.....	.....
4	28	19	31	20	31	29	29	34	(a)	36	51	42	29	.....	.....	.....	.....
24	50	35	51	39	54	44	49	58	45	62	72	56	38	.....	.....	.....	.....
48	60	43	60	49	65	51	65	76	51	73	79	62	41	.....	.....	.....	.....
72	67	49	66	54	71	55	76	87	55	80	83	65	43	.....	.....	.....	.....
96	73	53	71	59	77	59	86	96	58	84	85	67	44	.....	.....	.....	.....
120	78	56	74	63	81	63	93	104	60	88	87	69	45	.....	.....	.....	.....
144	81	59	77	65	83	65	99	109	61	91	89	71	45	.....	.....	.....	.....
168	85	61	79	68	86	67	105	114	62	93	90	72	46	.....	.....	.....	.....
192	87	63	81	70	89	69	109	118	63	95	91	73	46	.....	.....	.....	.....
216	90	65	83	72	91	71	113	122	64	97	93	74	47	.....	.....	.....	.....
240	92	66	84	73	93	72	117	125	64	99	94	75	47	.....	.....	.....	.....

EXPERIMENT III (MOISTURE CONTENT=1.5 HYGROSCOPIC COEFFICIENT)

1	18	17	18	10	19	18	20	20	16	24	34	34	22	.....	.....	.....	.....
2	23	21	23	14	25	23	26	28	21	32	43	42	27	.....	.....	.....	.....
3	27	23	27	17	30	27	32	33	25	39	49	47	30	.....	.....	.....	.....
4	30	26	30	20	34	30	36	38	28	44	54	51	34	.....	.....	.....	.....
24	51	38	53	39	65	48	73	79	48	78	81	72	49	.....	.....	.....	.....
48	62	(b)	64	48	80	58	95	102	57	94	88	80	55	.....	.....	.....	.....
72	69	.....	71	56	91	(b)	109	117	63	104	93	84	58	.....	.....	.....	.....
96	75	.....	77	60	99	.....	120	127	66	111	96	87	61	.....	.....	.....	.....
120	79	.....	80	63	104	.....	128	135	69	116	99	89	63	.....	.....	.....	.....
144	83	.....	83	66	108	.....	135	141	72	121	100	91	64	.....	.....	.....	.....
168	86	.....	86	69	112	.....	140	147	73	126	102	92	65	.....	.....	.....	.....
192	89	.....	87	70	116	.....	145	152	75	129	103	93	66	.....	.....	.....	.....

[a] No record. [b] The color of the soil prevented any observation of a further rise.

RELATION OF RISE TO INITIAL MOISTNESS

In general, the movement throughout the period of observation was most rapid in the soils when in the moistest condition. To this generalization soils A, C, and I form partial exceptions, and with all of these the duplicates were very closely concordant; with C and I the rise was least in the intermediate and greatest in the driest condition. With the soils other than these three we find, on comparing the data from Experiment II with those from Experiment I, that with the exception of soil E the movement was more rapid in the drier condition. There thus

appears to be no definite dependence of the rise upon the initial moistness of the soils (fig. 2).

DISTRIBUTION OF MOISTURE IN THE COLUMNS

The moisture content of the upper 2-inch section of the moistened portion of the soil column, the height of which is shown in Table XVIII, is reported in Table XX.

The eight finest textured soils showed the highest percentage of moisture at the head of the advancing moist layer when used in the driest condition. The coarser textured members, K, L, and M, showed no regularity.

In the soils other than the sands, N, O, P, and Q, the moisture condition of this moist layer shows a close relation to the moisture retentiveness (2). From this we may conclude that the advancing moist layer in such soils carries a moisture content approximately equal to the moisture equivalent, or from 1.7 to 2.5 times the hygroscopic coefficient.

TABLE XX.—*Moisture content of the uppermost 2-inch section of the moistened portion of the soil column after the base of the column had been in contact with water for 8 to 10 days*

Soil.	Hygroscopic coefficient.	Moisture equivalent.	Total water.			Ratio of moisture content to hygroscopic coefficient.			Ratio of moisture content to moisture equivalent.		
			Experiment I	Experiment II	Experiment III	Experiment I	Experiment II	Experiment III	Experiment I	Experiment II	Experiment III
			P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
A	13.3	29.5	30.4	25.7	24.1	2.3	1.9	1.8	1.0	0.9	0.8
B	12.9	25.8	26.6	22.1	.....	2.1	1.7	.....	1.0	.9	.....
C	10.5	24.1	24.4	22.0	20.7	2.1	2.1	2.0	1.0	.9	.9
D	10.2	27.8	24.9	20.0	20.0	2.2	2.3	2.0	.9	.8	.7
E	10.1	22.5	24.2	20.7	20.6	2.4	2.0	2.0	1.1	.9	.9
F	10.0	19.2	20.1	17.2	18.6	2.0	1.7	1.9	1.0	.9	1.0
G	8.2	21.2	22.6	17.5	18.0	2.8	2.1	2.2	1.1	.8	.8
H	7.6	19.7	21.1	17.2	18.3	2.8	2.3	2.4	1.1	.9	.9
I	7.1	16.8	15.0	15.9	15.7	2.1	2.2	2.2	.9	.9	.9
J	5.6	13.5	14.3	12.7	14.3	2.2	2.3	2.6	1.1	.9	1.1
K	3.4	7.5	8.8	8.6	8.1	2.6	2.5	2.4	1.2	1.1	1.1
L	3.4	7.2	7.6	.....	8.3	2.2	.....	2.4	1.1	.....	1.1
M	3.3	7.9	9.0	9.0	6.1	2.7	2.7	1.8	1.1	1.1	.8
N	1.6	3.0	6.7	.....	.....	4.2	.....	.....	2.2	.....	.....
P	.9	1.6	5.2	.....	.....	5.8	.....	.....	3.2	.....	.....
Q	.6	1.5	4.7	.....	.....	7.8	.....	.....	3.1	.....	.....

RELATION OF PENETRATION TO CAPILLARY RISE

When the soils are arranged in the order of the distance of penetration or of the rate at the end of any interval and also of the distance and rate of capillary rise, the relative positions of the various soils show no similarity. This is well illustrated by the curves for soils H and M in figures 1 and 2. In these two soils the downward movement was very similar (Table XVI), while in capillary rise they showed little similarity. The same lack of similarity was shown by the data of Von Liebenberg obtained from investigations with dry soils (11, tables 3 and 15).

INFLUENCE OF ORGANIC MATTER CONTENT

In the case of the four pairs of soils D–A, C–G, E–H, and M–L (Table VI), the surface soil and the subsoil are of similar origin and of at least somewhat similar hygroscopicity, while the organic matter in the former is from three to eight times as high as in the latter. The rate and distance of penetration showed no distinct dependence upon the relative amounts of organic matter, but with the capillary rise the rate after the first day and the final height attained were, in the case of each of the four pairs, greater in the case of the surface soil in all three moisture conditions.

SUMMARY

The relation of the rate and distance of the downward movement of water in a soil to its texture has, up to the present, received very little attention. Many investigators have studied the influence of the texture upon the rate and distance of the upward movement from a water surface, but in nearly all cases the soils have been used in an air-dry state, a condition very rarely met with in nature at any considerable distance below the surface; these studies have led to the conclusion that the finer the texture the slower is the rise at first, but the greater the final distance reached before movement ceases. Data showing the relation of rate and distance of rise to the actually determined hygroscopicity appear entirely wanting. The influence of the initial moistness upon the rate and distance of rise has been studied with only soils of low hygroscopicity, and even with these the results obtained by the different investigators are too discordant to justify definite conclusions.

Under natural conditions in the humid region the moisture content of the surface foot of soil rarely is as low as the hygroscopic coefficient, and in semiarid regions it seldom falls below this value.

Seventeen soils, ranging from a coarse sand with a hygroscopic coefficient of 0.6 to a silt loam with one of 13.3, were placed in cylinders in three different degrees of moistness, 0.5, 1.0, and 1.5 times the hygroscopic coefficient, 1 inch of water was applied to the surface, the rate of movement during five days observed, and finally the moisture distribution at the end of this period determined.

When placed in the cylinders the finer-textured soils showed a lower apparent specific gravity than the coarser, but within groups of somewhat similar texture this value was found to show no direct dependence upon the hygroscopicity.

The moisture content of the moistened layer, even at the end of the first hour, was only from one-half to two-thirds the maximum water capacity, which shows that the latter has little significance as a direct index of the moisture retentiveness of a soil.

The moisture content of the moistened layer fell much more rapidly with the finer-textured soils, at the end of 24 hours it being only between 2 and 3 times the hygroscopic coefficient, while in the coarser soils it

varied from 3 to 10 times the coefficient. At the end of the five days equilibrium had been practically attained in the finer-textured soils, but in the coarser ones this was far from being the case. The coarser the soil the more slowly was equilibrium reached.

The rate of penetration showed little dependence upon the hygroscopicity, but was definitely affected by the moistness, the higher the initial moisture content of any soil within the limits employed the more rapid being the downward movement of water.

The distance of penetration during the five days following the application of water increased with the initial moistness of the soil, but was not closely related to the hygroscopicity, owing partly to the slowness with which equilibrium is attained in the coarser soils.

With the finer-textured soils the water content of the moistened layer was not distinctly affected by the initial moistness, but with the coarser members the drier the soil the wetter was the moistened layer.

Provided that a period of high evaporation is to precede the next rain, the character of the weather immediately following a rain will have a greater effect upon the loss of moisture by evaporation in the case of a coarse than of a fine-textured soil.

Glass tubes were filled with the same soils in the same three degrees of moistness and the lower ends placed in contact with water kept at a constant level. The rate of rise during 8 or 10 days was observed and the moisture in the uppermost layer of the moistened portion of the soil column at the end of this period determined.

At first the rise was most rapid in the soils of low hygroscopicity, but the difference gradually lessened until those of intermediate hygroscopicity were in the lead. There was no definite dependence of the rise upon the hygroscopicity.

No definite dependence of the rate of rise upon the initial moistness was shown, it being, in the case of the three moisture conditions studied, generally most rapid in the moistest condition and slowest in the intermediate.

All the finer-textured soils showed the highest percentage of moisture at the head of the advancing moist layer when used in the driest condition, but the coarser members showed no difference. The moisture content of this moist layer shows a rather constant relation to both the hygroscopic coefficient and the moisture equivalent, being similar to the moisture retentiveness of the same soils.

The relative rates and distances of penetration in the different soils are not similar to the relative rates and heights of capillary rise.

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BIOLOGIC FORMS OF PUCCINIA GRAMINIS ON CEREALS AND GRASSES[1]

By E. C. STAKMAN, *Head of the Section of Plant Pathology, Division of Plant Pathology and Botany, Department of Agriculture, University of Minnesota*, and F. J. PIEMEISEL, *Scientific Assistant, Office of Cereal Investigations, Bureau of Plant Industry, United States Department of Agriculture*

COOPERATIVE INVESTIGATIONS BETWEEN THE AGRICULTURAL EXPERIMENT STATION OF THE UNIVERSITY OF MINNESOTA AND THE BUREAU OF PLANT INDUSTRY OF THE UNITED STATES DEPARTMENT OF AGRICULTURE

INTRODUCTION

The question as to which biologic forms of *Puccinia graminis* Pers. occur on wild grasses is important. Considerable work has been done on the biologic forms of stemrust on the common cultivated cereal grasses, and some has also been done on the relation of the rust on wild grasses to that on cereals. However, on account of the scientific and practical importance of obtaining further information on the identity of the biologic forms of *P. graminis* on wild grasses and the importance of determining the degree of plasticity of these forms when subjected to changed environments, preliminary work on the problem was begun at the Agricultural Experiment Station of the University of Minnesota in the spring of 1913. Since 1915 the work has been done in cooperation with the Office of Cereal Investigations, Bureau of Plant Industry, United States Department of Agriculture. The cooperative arrangement has made possible more extensive work and has also given it broader scope.

The object of the work was to determine first the wild hosts for the various biologic forms of *P. graminis*. An attempt was made to determine the frequency of association of any given biologic form with a particular host, the possible geographical localization of biologic forms, the possible variation in parasitic capabilities of forms from different hosts and different localities, and the possible relation of the facts obtained to cereal-rust epidemiology. In order to obtain facts of value on the last-named phase of the problem, it was necessary to make observations on the origin of the early spring infections, the relation of barberries (*Berberis* spp.) to the occurrence and behavior of rust, and to

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investigate thoroughly the possibility of changing the parasitic tendencies and capabilities of any biologic form by the use of so-called bridging hosts, by confining a form for a long period of time to uncongenial hosts in an attempt to increase the virulence, and by determining the effect of ecological factors on the rust. The results of the studies of the plasticity of biologic forms will be published in a subsequent paper. The present paper deals mainly, therefore, with the identity of the biologic forms on various hosts.

The problem has received considerable attention both in the United States and in foreign countries. Hitchcock and Carleton (15, 16),[1] Carleton (5, 6, 7), Arthur (1, 2), Bolley (3), Bolley and Pritchard (4), Freeman and Johnson (14), Johnson (19), Pritchard (22, 23), Mercer (21), Stakman (24, 25), Stakman and Jensen (26), and Stakman and Piemeisel (27, 28, 29), have done work on various phases of the question in the United States. The taxonomic work of Arthur and the extensive inoculation experiments of Carleton, followed by the work of Freeman and Johnson with the biologic forms on cereals, have especially laid the foundation for further work. In Europe Eriksson (8–11), Eriksson and Henning (12, 13), and Jaczewski (18) have made extensive investigations. The results are well summarized by Klebahn (20). Although the results obtained by these investigators are usually in general agreement, yet there often are differences which indicate clearly the necessity for thoroughgoing work in different regions. A detailed discussion of these results, in so far as they bear directly on the problem under consideration, will be postponed until after the writer's results are given. Two examples, however, may be cited to show the necessity for further work.

Jaczewski (18, p. 353) states that in Russia *Dactylis glomerata* is immune to *P. graminis avenae*, but is infected by *P. graminis secalis*. Eriksson (11, p. 601), on the other hand, found that in Sweden the same grass is susceptible to *P. graminis avenae* and Carleton (6, p. 63) found the same to be true in this country. Carleton (6, p. 54) also reports successful infection with *P. graminis tritici*. Again, Carleton (6, p. 64) gives the following as hosts for *P. graminis avenae:* Oats (*Avena sativa patula*, *A. sativa orientalis*, and *A. sativa nuda*—cultivated varieties), *Dactylis glomerata*, and *Arrhenatherum elatius*. Pritchard (22, p. 181) obtained results indicating that one form of rust infected rye, oats, *Hordeum jubatum*, *Agropyron tenerum*, *A. repens*, and *Avena fatua*. Of these, Carleton (6, p. 56–57) found that *Hordeum jubatum* was certainly a host for *P. graminis tritici* and *Agropyron tenerum* probably so, whereas neither was a host for *P. graminis avenae*, facts which have been confirmed by the writers. Moreover, the writers have been unable to infect *Agropyron tenerum* and *Hordeum jubatum* with *P. graminis* from oats,

[1] Reference is made by number to "Literature cited," p. 493–495.

although it is quite probable that *Hordeum jubatum* may be infected very rarely and weakly. Carleton's work was done largely in the southern wheat-growing area of the Mississippi Valley, while Pritchard's was done in North Dakota. This suggests a possible geographical specialization of the stemrust, and the writers therefore attempted to obtain inoculating material from as many different sources as possible.

REGION COVERED BY THE SURVEY

The work reported in this paper was confined mainly to the upper Mississippi Valley, especially Minnesota, North Dakota, South Dakota, northern Iowa, northern Nebraska, northeastern Wyoming, Montana, and part of the Red River Valley of Manitoba, Canada. Preliminary work was also done in a small part of the intermountain area of the Northwest, especially in Washington and Idaho. It would be highly desirable to extend the work over the cereal-producing regions of the entire United States and Canada.

EXPERIMENTAL METHODS

The rusted grasses were collected in the field, kept in separate envelopes, and immediately sent to the Minnesota Experiment Station, where all inoculations were made. Great care was always taken to avoid any mixing of spores on different grasses. When collecting, the hands were thoroughly washed after each species of grass was handled; or, when this was impossible, the grass was grasped with the collecting envelope as a protection against contaminating the hands with spores.

Inoculations were usually made with comparatively fresh uredinio-spores, although it was sometimes necessary to use rather old material. Inoculations were made in a few cases a month or longer after the grasses had been collected. The viability of the spores had sometimes been impaired somewhat, but at other times they germinated readily. In making the inoculations every precaution was taken to maintain aseptic conditions, and the writers are confident that erroneous conclusions were not drawn as a result of accidental infection when working with different strains. Usually one person worked with only one strain during the day, although it was sometimes necessary to work with more. The plants to be inoculated were grown in a greenhouse compartment where no rust was kept. They were grown under cages made of two layers of a fine-mesh muslin with a dead-air space between the two.

The inoculations on cereals were all made on the leaves or sheaths of seedlings. It was found that the results were comparable with those obtained on older plants. The inoculations on grasses were sometimes made on old plants. In general, the best results were obtained on young, vigorously growing plants, although with some grasses the opposite seemed to be true. Although the writers observed no cases of immunity

due to age, the rust was nevertheless often distinctly more virulent on younger or older plants, depending on the peculiarity of the grass.

The plants to be inoculated were moistened either with an atomizer or by rubbing water on with the fingers. The spores were applied with a flat inoculating needle in such a way as not to injure the leaves. After inoculation the plants were placed in pans of water under thoroughly cleaned bell jars, where they were left for 48 hours. They were then removed and placed on ordinary greenhouse benches. During warm weather, when it was necessary to keep the ventilators open much of the time and there was some danger of contamination with wind-borne spores, each strain was kept under a separate muslin cage such as those under which the seedling plants were grown. A cage was not used again for another strain of rust until first thoroughly disinfected with formaldehyde solution.

All necessary precautions were taken to dispose properly of infected material, and the greenhouse benches were drenched frequently with a strong solution of copper sulphate in order to kill any spores which might have fallen from the leaves. Accidental infections were almost entirely avoided, as is shown by the fact that three different biologic forms were kept more than two years, and many others were kept for shorter periods, without any contamination whatever.

Whenever there was any reason to suspect the presence of more than one biologic form on a host as a result of inoculations with urediniospores collected in the field, all available methods were used to isolate these forms before drawing any conclusions. Further attention will be paid to this in a discussion of the specific results obtained.

The following varieties of cereals were used, except where otherwise specified: Oats—Improved Ligowa, Minnesota No. 281; barley—Manchuria, Minnesota No. 105; wheat—Bluestem, Minnesota No. 169; rye—Swedish, Minnesota No. 2. Most of the grass seeds were obtained from the Minnesota Seed Laboratory. A few were obtained from the Montana Seed Laboratory. The seed of the primitive barleys was furnished by Dr. H. V. Harlan, of the Office of Cereal Investigations, United States Department of Agriculture.

RESULTS OF SURVEY

The results of the inoculations made directly from the grasses collected in the field are given in Tables I to XXVII. The direct inoculations constitute only a small part of the work actually done. The various rusts were often cultured in the greenhouse for varying lengths of time, and as many inoculation experiments were made as seemed necessary to establish the identity of the rust completely and to determine whether it was in any way atypical. The results of these inoculations are given, with the discussions of the various biologic forms.

The following biologic forms are discussed in the paper: *Puccinia graminis tritici* Erikss. and Henn.; *P. graminis tritici compacti*, form. nov.; *P. graminis secalis* Erikss. and Henn.; *P. graminis avenae* Erikss. and Henn.; *P. graminis phleipratensis*, comb. nov. = (*P. phleipratensis* Erikss. and Henn.); *P. graminis agrostis* Erikss.

KEY TO TABLES I–XXVII

In Tables I to XXVII "Place" refers to the place of collection, and "Date," to the date on which inoculations were made. The plants inoculated are listed in the same line with place and date and the results are given in the form of a fraction. The denominator indicates the number of leaves inoculated and the numerator the number which developed uredinia. The figures after the semicolon give the number of leaves which were distinctly flecked. The degree of infection is not indicated in the tables, but it is given in the discussions following the tables.

TABLE I.—*Results of inoculations with urediniospores from Agropyron caninum (L.) Beauv.*

No.	Place.	Date.	*Triticum vulgare.*	*Avena sativa.*	*Hordeum vulgare.*	*Secale cereale.*	*Hordeum jubatum.*
		1914					
1	St. Paul, Minn.....	Aug. 25	$\frac{2}{20}$	$\frac{0}{20}$	$\frac{5}{20}$	$\frac{4}{20}$	.....
		1915.					
2	.....do.....	Aug. 13	$\frac{0}{46}$	$\frac{0}{38}$	$\frac{30}{42}$	$\frac{18}{21}$	$\frac{1}{14}$
3	Mandan, N. Dak.....	Sept. 3	$\frac{19}{27}$	$\frac{0}{5}$	$\frac{9}{14}$	$\frac{5}{12}$;2	.....
4	Emerson, Manitoba, Canada.....	Aug. 21	$\frac{18}{18}$	.....	.....	$\frac{2}{9}$	.....
5	Winnipeg, Manitoba, Canada.....	29	$\frac{20}{20}$	.....	.....	$\frac{4}{22}$;3	.....

P. graminis tritici compacti is a form recently described by the writers (29) as differing from other biologic forms in its action on most common wheats (*Triticum vulgare* Vill.). There seems to be no valid reason for not considering the timothy rust as a biologic form of *P. graminis*. Further discussion of biologic forms is given after Tables XXVIII to XXXIII.

Reference is sometimes made to strains of a biologic form. This means merely rust with a certain history and does not necessarily indicate that the so-called strain is different from the typical rust of the biologic form in question. For instance, if *P. graminis tritici* had been collected on *Agropyron tenerum* and *Hordeum jubatum* and the rust from each cultured separately in the greenhouse for a number of generations, the two would be known as strains.

It is quite evident from Table I that *Agropyron caninum* is a host for both *P. graminis tritici* and *P. graminis secalis*. It will be observed that in No. 2 only *P. graminis secalis* was obtained from the grass, while in No. 4 and 5 probably only *P. graminis tritici* was present, since the uredinia on rye were very small and were surrounded by dead leaf areas, thus being typical of the uredinia of *P. graminis tritici* on rye. It is possible that both biologic forms were present in No. 3, although the character of infection pointed to the probable presence of *P. graminis tritici* only.

While *Agropyron caninum* is fairly common in the region covered by the survey, it is probably of secondary importance. It is by no means as common as some of the other species of Agropyron, and, although often severely rusted, it can not be considered in the rank of first importance as a means of enabling the rust to spread to cereals.

TABLE II.—*Results of inoculations with urediniospores from Agropyron cristatum*

No.	Place.	Date.	*Triticum vulgare.*	*Avena sativa.*	*Hordeum vulgare.*	*Secale cereale.*
		1915.				
1	St. Paul, Minn.....	Sept. 10	$\frac{1}{13}$	$\frac{0}{19}$	$\frac{25}{28}$	$\frac{8}{16}$

The results of the one series of inoculations given in Table II show that *Agropyron cristatum* may be infected with both *P. graminis secalis* and *P. graminis tritici*. While only one uredinium developed on wheat, subsequent events show clearly that both forms were present on the grass when collected from the grass garden in which it was growing.

It will be noted in Table II that barley became heavily infected. The rust on the barley proved to be partly *P. graminis tritici* and partly *P. graminis secalis*, mostly the latter. This was shown by a number of successive transfers to barley, wheat, and rye. Both forms were eventually isolated and, after isolation, remained pure; although, if extensive inoculation experiments had not been made, it would have appeared that barley might enable *P. graminis secalis* to infect wheat.

It is quite apparent from Table III that the common form of stem-rust on *Agropyron repens* is *P. graminis secalis*. Of the 307 leaves of wheat which were inoculated only 3 developed uredinia, while not a single one of the various trials on rye was unsuccessful, although in a few cases not all of the inoculated leaves became infected. This is not surprising, however, since many of the inoculations were made during the hottest weather of the summer, when conditions for infection were unfavorable. Rye plants vary considerably in their susceptibility to *P. graminis secalis*, probably on account of their heterozygous character, and this naturally accounts for some of the variability of infection.

TABLE III.—*Results of inoculations with urediniospores from Agropyron repens (L.) Beauv.*

No.	Place.	Time.	*Triticum vulgare.*	*Avena sativa.*	*Hordeum vulgare.*	*Secale cereale.*	*Agropyron caninum.*	*Agropyron cristatum.*	*Agropyron imbricatum.*	*Agropyron smithii.*	*Agropyron repens.*	*Boutelloua curtipendula.*	*Bromus tectorum.*	*Elymus canadensis.*	*Elymus robustus.*	*Elymus virginicus.*	*Hordeum jubatum.*
		1915.															
1	St. Paul, Minn.	June 15	0/25	0/22; 1	15/15	14/14	.....	9/14	2/6	.....	.....	.....	.....	.....	.....	26/39	.....
2	.....do.....	June 22	0/35	0/42	43/44	31/32	.....	.....	.....	.....	.....	.....	0/22; fl	.....	.....	.....	.....
3	.....do.....	July 9	1/53	0/42	64/67	56/56	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
4	.....do.....	July 14	1/43	0/24	.....	12/19	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
5	.....do.....	July 19	0/25	0/21	27/30	26/27	.....	.....	.....	.....	.....	0/11	3/11	17/17	13/13	7/11	7/8
6	.....do.....	July 21	.....	0/43	45/45	16/16	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
7	Albert Lea, Minn.	July 24	0/22	0/28	42/42	38/38	5/8	.....	.....	7/7	.....	.....	0/7; 4	3/8	12/12	5/8	.....
8	St. Paul, Minn.	July 27	0/41	0/24	25/28	16/23	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
9	Montevideo, Minn.	July 29	0/18	0/11	5/15	4/9	.....	.....	.....	.....	.....	.....	.....	.....	4/7	.....	.....
10	St. Paul, Minn.	Aug. 12	1/46	0/13	30/30	13/22	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	10/16
11	Fargo, N. Dak.	Aug. 23	0/53	0/27	34/34	27/27	.....	.....	.....	.....	34/34	.....	.....	.....	.....	.....	4/4
12	Presque Isle, Me.	...do	0/34	0/29	24/26	18/18	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
		1916.															
13	McIntosh, Iowa.	July 8	0/11	.....	7/8	6/8	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
14	St. Paul, Minn.	July 17	0/11	.....	.....	5/14	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

Many inoculation experiments were made with known strains of *P. graminis secalis* and *P. graminis tritici* on *Agropyron repens*, and the results confirm the conclusions to be drawn from the results given in Table III. The grass is very susceptible to *P. graminis secalis*, while normal infection with *P. graminis tritici* is rare.

It is quite probable that the successful infections on wheat, recorded as No. 3, 4, and 10 (Table III), resulted from chance spores which may have been blown to the *Agropyron repens* before it was taken from the field. It is very doubtful whether uredinia actually were developed on the grass in the field. The reason for suspecting that they were not is that on the wheat leaves which became infected single uredinia were produced, indicating the probable source of infection as being one or, at most, a very few spores. If the infection had resulted from the spores taken from a uredinium, several uredinia would probably have developed on the wheat. There is evidence that *Agropyron repens* does not become infected with *P. graminis tritici* in nature even when opportunities for infection are very favorable. This is shown as a result of inoculations No. 14. The rusted grass plants were growing in a wheat plot which had been thoroughly and frequently sprayed with uredinio spores of *P. graminis tritici* in suspension in water. The wheat plants were all very heavily rusted, and it was supposed that the quack-grass plants might be infected with *P. graminis tritici* also, because they had been inoculated in the same way, but it will be seen by reference to Table III that such was not the case. Only *P. graminis secalis* occurred on the quack-grass plants.

Agropyron repens is very commonly and very heavily rusted with *P. graminis secalis*. It is often among the first of the grasses to become rusted in the spring. Severe epidemics may develop before other grasses become even moderately rusted.

It is quite apparent from Table IV that *Agropyron smithii* may be affected with both *P. graminis tritici* and *P. graminis secalis*. Artificial inoculations show that both can attack the grass about equally well, especially when young seedlings are inoculated. It is interesting to note that in No. 5 nearly every leaf of wheat, rye, and barley became infected. This might very easily at first glance indicate the occurrence of a single biologic form capable of attacking all three of these cereals. The original rust on the grass, however, was unquestionably a mixture of *P. graminis tritici* and *P. graminis secalis*. This is shown clearly in diagram 1. The rust on rye was transferred to rye or barley 14 successive times during a period of 8 months and wheat was inoculated 8 times, but no uredinia developed on any one of the 107 inoculated leaves. Both rye and barley, on the other hand, were easily infected, showing that the rust originally developed on rye was *P. graminis secalis*.

TABLE IV.—*Results of inoculations with urediniospores from Agropyron smithii Rydb.*

No.	Place.	Date.	*Triticum vulgare.*	*Avena sativa.*	*Hordeum vulgare.*	*Secale cereale.*	*Agropyron smithii.*	*Agropyron repens.*
		1914						
1	St. Paul, Minn.	Aug. 26	5/20	0/20	7/20	15/20	.....	.....
		1915						
2	.....do.....	Aug. 5	0/57	0/35	49/49	25/26	.....	.....
3	.....do.....	Aug. 13	3/21	0/14	6/8	6/10	2/5	.....
4	Mandan, N. Dak.	Aug. 27	10/10	0/10	12/13	1/13	5/6	0/20
5	La Moure, N. Dak.	Aug. 26	22/23	0/12	9/13	11/11	.....	.....
		1916						
6	Denver, Colo.	Aug. 5	0/20	.....	.....	0/14	.....	.....
7	Devils Lake, N. Dak.	Sept. 19	1/13	.....	.....	13/16	.....	.....
8	Minot, N. Dak.	Sept. 20	22/22	0/21	.....	0/20;3	.....	.....
9	Glasgow, Mont.	Sept. 20	33/34	.....	.....	3/30;1	.....	.....
10	Havre, Mont.	Sept. 20	14/15	.....	.....	0/17;1	.....	.....
11	Williston, N. Dak.	Sept. 22	20/20	.....	12/13	0/18;1	.....	.....
12	Newcastle, Wyo.	Oct. 12	0/19	.....	.....	0/15;2	.....	.....

From the rusted wheat 18 successive transfers were made during a period of 10 months, 17 of which were to barley Only about one-half of the total number are shown in the diagram; the other results were similar to those shown here. Wheat and barley were easily and heavily infected when inoculated, while rye and *Agropyron repens* were weakly infected. The uredinia of *P. graminis tritici* on rye are very small and are usually surrounded by dead areas, thus being easily distinguishable from those of *P. graminis secalis*. The uredinia of *P. graminis tritici* on *A. repens* are as a rule very small, although there seems to be considerable variation. Whether this is on account of the condition of the seedlings or the conditions for infection is still doubtful. It is quite clear from the behavior of the rust that this form was *P. graminis tritici*.

The reason why only 12 of the 16 leaves of wheat inoculated with the rust from *Agropyron repens* developed uredinia, whereas 100 per cent of the leaves became infected in the subsequent set of inoculations, is that the uredinia on *A. repens* were very small, thus necessitating light inoculation. Four of the wheat leaves therefore escaped infection. Those

DIAGRAM 1.—Results of successive transfers of rust from wheat and rye in No. 5, Table IV.[a]

Puccinia graminis from *Agropyron smithii* (La Moure, N. Dak.).

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leaves which became infected, however, developed large uredinia, thus furnishing ample material for the next inoculations.

It is especially interesting to notice the results of the successive transfers of the wheat rust from rye to rye. The rust develops very poorly, and, since the amount of the inoculating material as a rule decreases with each successive transfer, the rust is finally lost. It is also interesting to note that barley, a host for both forms of rust, did not change the parasitic capabilities of either.

The diagram shows, then, that on the original *Agropyron smithii* both *P. graminis tritici* and *P. graminis secalis* were present. For this reason successful infection resulted on wheat, rye, and barley. But when transfers were made from rye to barley, rye, and wheat, only the first two became infected. When, on the other hand, transfers were made from the rusted wheat, wheat and barley were infected, and rye only occasionally produced small, characteristic uredinia, which are distinguishable from those of *P. graminis secalis* both in appearance and performance. Both rusts easily infected barley and *A. smithii*.

Agropyron smithii is very abundant and is very often rusted. In 1916 it was very heavily rusted throughout the Northwestern States and southern Manitoba, Canada. There has been no difficulty in finding badly rusted plants during the last five years. On account of the fact that the grass is a host for two distinct biologic forms, and possibly a third, it is probably important in stemrust distribution.

TABLE V.—*Results of inoculations with urediniospores from Agropyron spicatum (Pursh.) Rydb.*

No.	Place.	Date.	*Triticum vulgare.*	*Avena sativa.*	*Hordeum vulgare.*	*Secale cereale.*
		1916.				
1	Glasgow, Mont.....	Sept. 18	$\frac{13}{14}$	$\frac{0}{12}$	$\frac{12}{16}$	$\frac{2}{14}$; 1

Only one set of inoculations was made with *Agropyron spicatum* from east of the Rocky Mountains, although it was quite badly rusted in most localities visited from Glasgow, Mont., west to the mountains. The rust was ordinary *P. graminis tritici*. *P. graminis* was also collected on the grass west of the mountains, but the spores were not viable when inoculations were made. Unfortunately, therefore, the identity of the biologic form of the rust in that region could not be determined with certainty (Table V).

In every one of the 15 trials recorded in Table IV, some wheat became infected, indicating that *P. graminis tritici* often occurs in many regions on *Agropyron tenerum*. On the other hand, *P. graminis secalis* developed only as a result of inoculations 1, 2, and 7, and some of the uredinia in No. 7 were unquestionably *P. graminis tritici*.

TABLE VI.—*Results of inoculations with urediniospores from Agropyron tenerum Vasey*

No.	Place.	Date.	*Triticum vulgare.*	*Avena sativa.*	*Hordeum vulgare.*	*Secale cereale.*	*Agropyron repens.*	*Agropyron caninum.*	*Hordeum jubatum.*
		1914.							
1	St. Paul, Minn.....	Aug. 20	2/20	0/20	5/20	13/20	.....	.....	.....
		1915.							
2	.....do.....	Aug. 12	16/82	0/38	55/61	40/61	.....	.....	12/19
3	Valley City, N.Dak.	Aug. 21	2/10	0/14	11/14	2/11	.....	.....	.....
4	Dickinson, N. Dak.	Aug. 27	1/8	0/14	10/12	.....	16/16	13/13	.....
		1916.							
5	St. Paul, Minn.....	July 17	1/10	.....	5/10	0/25	.....	.....	.....
6	Crookston, Minn....	Aug. 21	12/12	.....	.....	0/9; 2	.....	.....	.....
7	.....do.....	Aug. 21	30/30	.....	.....	7/23	.....	.....	.....
8	Emerson, Manitoba.	Aug. 21	25/25	.....	11/11	3/17	.....	.....	.....
9	Glasgow, Mont.....	Sept. 18	13/19	0/20	.....	0/12; 2	.....	.....	.....
10	Williston, N. Dak..	Sept. 19	.....	0/16	[a]20/20	0/11; 2	.....	.....	.....
11	Havre, Mont.....	Sept. 20	14/14	.....	.....	1/19; 6	.....	.....	.....
12	Minot, N. Dak.....	Sept. 21	.....	0/17	[a]23/23	.....	.....	.....	.....
13	Glasgow, Mont.....	Sept. 22	22/22	.....	.....	0/21; 1	.....	.....	.....
14	.....do.....	Sept. 30	15/21	.....	.....	2/16	.....	.....	.....
15	Newcastle, Wyo....	Oct. 2	8/10	0/23	.....	2/13; 4	.....	.....	.....

[a] *P. graminis tritici;* both transferred readily to wheat, not rye.

Inoculations on *Agropyron tenerum* with known strains of *P. graminis tritici* and *P. graminis secalis* show very clearly that it is very susceptible to both forms, thus confirming the results of the inoculations with rust collected in the field (Table VI).

Agropyron tenerum is almost always rusted, sometimes very severely. In the summer of 1916 especially it was almost universally very heavily rusted in Minnesota, North Dakota, Montana, northeastern Wyoming, northwestern Nebraska, and northern Iowa. The same was also true in the Red River Valley in Manitoba, at least as far north as Winnipeg. In 1915 the grass was severely rusted in Minnesota and North Dakota, and very probably throughout the northern wheat-growing area.

There can be but little question that *Agropyron tenerum* is very instrumental in spreading and possibly also in the overwintering of the wheat stemrust and the rye stemrust. It is especially important because it is a congenial host for at least these two common biologic forms and can also be easily infected by *P. graminis tritici compacti.*

TABLE VII.—*Results of inoculations with urediniospores from Agrostis alba L.*

No.	Place.	Date.	*Triticum vulgare.*	*Avena sativa.*	*Hordeum vulgare.*	*Secale cereale.*	*Agrostis alba.*	*Phleum pratense.*
		1914.						
1	St. Paul, Minn.....	Oct. 23	0/20	0/24	0/20	1/22	.....	.....
		1915.						
2	Albert Lea, Minn.....	July 24	0/36	0/34	1/42	0/35	.....	.....
3	St. Paul, Minn.....	Aug. 17	0/19	12/21	12/36	1/33	.....	.....
4	.....do.....	Sept. 8	0/27	1/34	3/42	0/33	.....	.....
5	.....do.....	Sept. 10	0/28	9/33	1/20	0/14	.....	.....
		1916.						
6	.....do.....	July 7	0/12	0/23	0/5	1/23	.....	0/20
7	.....do.....	July 17	.....	0/16	1/20	0/10	.....	.....
8	.....do.....	Aug. 14	0/19	6/28	9/16	1/22	.....	.....
9	Hinckley, Minn.....	July 21	0/13	0/20	2/13	0/16	.....	.....
10	Crookston, Minn.....	Aug. 21	.....	0/9	.....	.....	30/30	0/38

The stemrust on *Agrostis alba* looks somewhat like *P. graminis phleipratensis.* It infects the cereals in somewhat the same way, and it was at first thought that possibly the rust was *P. graminis phleipratensis*, especially since the urediniospores are nearly equal in size. However, the rust seemed incapable of infecting timothy, and morphologically it differed enough from *P. graminis phleipratensis* to render any idea of the identity of the two rusts untenable. The rust is no doubt *P. graminis agrostis* Erikss., since it infects barberry readily. It is capable of infecting various grasses and oats, barley, and rye. On the three cereals the infection is very weak and resembles that caused by timothy rust very much. The uredinia were always very distinct, but very small. They were usually about 0.25 mm. in diameter, round or slightly elongate, and were not surrounded by large, dead areas as is so often the case when a biologic form develops slightly on an uncongenial host. From the character of the infection it seems quite improbable that *P. graminis agrostis* infects any of the cereals in the field, except possibly very

occasionally. *A. alba* has, however, been infected by *P. graminis avenae* in the greenhouse, although the writers have not found this form on it in the field. It is possible but not demonstrated, therefore, that it may be important as a host for *P. graminis avenae* (Table VII).

TABLE VIII.—*Results of inoculations with urediniospores from Agrostis exarata Trin.*

No.	Place.	Date.	*Triticum vulgare.*	*Avena sativa.*	*Secale cereale.*	*Calamagrostis canadensis.*
		1916				
1	Whitefish, Mont.....	Sept. 30	$\frac{0}{19}$	$\frac{24}{24}$	$\frac{3}{25}$; 2	$\frac{14}{14}$

Agrostis exarata was heavily rusted in a number of localities, especially in valleys in western Montana. The rust was evidently *P. graminis avenae*. It has been used in many inoculation experiments in the greenhouse, and, although it apparently is an ordinary strain in most respects, the morphology of the urediniospores is slightly different from that of some of the other strains. No sharp differences in parasitic capabilities have yet been noticed (Table VIII).

TABLE IX.—*Results of inoculations with urediniospores of Agrostis stolonifera Vasey*

No.	Place.	Date.	*Triticum vulgare.*	*Avena sativa.*	*Hordeum vulgare.*	*Secale cereale.*	*Agrostis alba.*	*Agrostis stolonifera.*	*Agropyron caninum.*	*Phleum pratense.*
		1914.								
1	St. Paul, Minn.	Aug. 26	$\frac{0}{20}$	$\frac{0}{20}$	$\frac{0}{20}$	$\frac{0}{20}$	.....	.....	.....	.....
2	.....do.....	Oct. 7	$\frac{0}{8}$	$\frac{0}{21}$	$\frac{2}{19}$	$\frac{1}{19}$	.....	.....	.....	.....
		1915.								
3	.....do.....	Sept. 17	$\frac{0}{23}$	$\frac{2}{15}$	$\frac{0}{22}$	$\frac{0}{20}$	.....	.....	.....	$\frac{0}{5}$
		1916.								
4	.....do.....	Aug. 30	.....	.....	.....	.....	$\frac{60}{60}$	$\frac{50}{50}$	$\frac{7}{7}$	.....
5	.....do.....	Sept. 2	$\frac{0}{20}$	$\frac{7}{22}$	.....	$\frac{2}{25}$	.....	.....	.....	.....

DIAGRAM 2.—Results of inoculations from uredinia produced in No. 4, Table IX.

P. graminis agrostis from *A. stolonifera*:
- *A. stolonifera* $\frac{50}{50}$ — Wheat $\frac{0}{34}$
- *A. canina* $\frac{7}{7}$ — Wheat $\frac{0}{19}$
- *A. alba* $\frac{60}{60}$ — *Calamagrostis canadensis* $\frac{3}{45}$

DIAGRAM 3.—Results of inoculations from uredinia produced on oats and rye in No. 5, Table IX.

P. graminis agrostis from *A. stolonifera*:
- Oats $\frac{7}{22}$ — Oats $\frac{2}{15}$ — Oats $\frac{0}{7}$
- Rye $\frac{\infty}{25}$ — Rye — $\frac{0}{4}$

Only the three species of Agrostis (Table IX) were really susceptible to *P. graminis agrostis* from *A. stolonifera*. The cereals were infected in much the same manner as were those inoculated with the rust from *A. aiba*. The character of the infection was the same. None of the cereals was a congenial host. The uredinia were all very small, but were not surrounded by much dead leaf tissue. Diagram 3 shows that the rust develops only weakly on oats and rye and does not acquire increased virulence as a result of successive transfers. None of the biologic forms commonly found on cereals was found on *A. stolonifera*, although there is reason to suspect that it can be infected naturally by *P. graminis avenae*, since successful transfers were made in the greenhouse.

RESULTS OF INOCULATIONS WITH UREDINIOSPORES FROM AVENA SATIVA

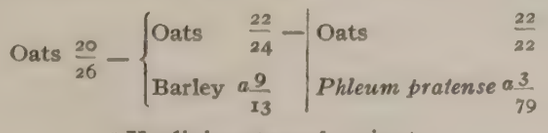
Oats affected with stemrust were collected at various places in Minnesota, North Dakota, and Montana. Inoculations were usually made only on oats, however, and the resulting rust kept as stock cultures. The results are included, therefore, in Table XXXI. Only *P. graminis avenae* was found.

TABLE X.—*Results of inoculations with urediniospores from Anthoxanthum pueili Lecoq. and Lamotte*

No.	Place.	Date.	*Triticum vulgare.*	*Avena sativa.*	*Hordeum vulgare.*	*Secale cereale.*
		1914.				
1	St. Paul, Minn.....	Aug. 23	$\frac{0}{20}$	$\frac{0}{20}$	$\frac{0}{20}$	$\frac{0}{20}$
		1916.				
2	Pullman, Wash.....	Sept. 30	$\frac{0}{19}$	$\frac{20}{26}$	.....	$\frac{0}{18}$

Further inoculations were made with the rust developed on oats. The results are given in diagram 4.

DIAGRAM 4.—Results of inoculations with urediniospores developed on oats recorded in Table X.



[a] Uredinia extremely minute.

Only a small number of inoculations were made with *P. graminis* from *Anthoxanthum puelli*, but from the results given above, it seems clear that the grass may be a host for *P. graminis avenae*. A number of inoculations with urediniospores of *P. graminis avenae* were made on seedlings of the grass. Some resulted in successful infection, while others did not.

The fact is as yet unexplained. The failure of the inoculations in 1914 was probably due to the fact that the rust on the grass was old.

TABLE XI.—*Results of inoculations with urediniospores from Avena fatua L.*

No.	Place.	Date.	*Triticum vulgare.*	*Avena sativa.*	*Hordeum vulgare.*	*Secale cereale.*
		1916.				
1	Williston, N. Dak.	Sept. 18	.....	29/31	1/21; 1	.....
2	Glasgow, Mont.	Sept. 22	3/22	.....	5/24	3/19
3	Pullman, Wash.	Sept. 30	.....	20/21	5/18; 4	.....

Avena fatua can be as easily infected with *P. graminis avenae* as *A. sativa* itself, and is often infected with the stemrust of oats in the field (Table XI). The writers have observed it very often in different localities. Apparently the rust developed on wheat was *P. graminis tritici*. Successful infection can be very easily explained by the fact that the *Avena fatua* plants from which inoculations were made were growing with *Agropyron tenerum* and *A. smithii*, both of which were badly affected with *P. graminis tritici*. The *A. fatua* plants might easily have touched the Agropyrons, thus becoming contaminated with *P. graminis tritici*. The rust developed on barley and rye was undoubtedly *P. graminis avenae*, since it easily transferred to oats.

A. fatua is also a congenial host for the crownrust of oats. The grass was found quite often heavily rusted.

TABLE XII.—*Results of inoculations with urediniospores from Dactylis glomerata L.*

No.	Place.	Date.	*Triticum vulgare.*	*Avena sativa.*	*Hordeum vulgare.*	*Secale cereale.*	*Hordeum jubatum.*	*Dactylis glomerata.*	*Agropyron caninum.*	*Agropyron smithii.*	*Phleum pratense.*
		1914.									
1	St. Paul, Minn.	Aug. 22	0/20	11/19	0/20	0/20	.....	.....	.....	.....	.....
		1915.									
2	Ramsey County, Minn.	Aug. 17	0/21	17/17	6/15	1/14	.....	.....	.....	.....	.....
3	.....do.....	Aug. 19	0/28	5/5	3/22	1/19	0/8	12/12	0/16	0/4	.....
		1916.									
4	Ames, Iowa	July 1	.....	0/25	0/15	.....	.....	.....	.....	.....	4/20
5	Long Beach, Cal.	July 8	0/6	0/13	.....	0/8	.....	.....	.....	.....	0/26
6	St. Paul, Minn.	Aug. 24	0/19	26/36	3/26	1/37; 3	.....	.....	.....	.....	.....

Dactylis glomerata may be affected with either *P. graminis avenae* or *P. graminis phleipratensis* in the field (Table XII). It will be noticed that the grass collected at Ames, Iowa, was affected with *P. graminis phleipratensis*. It is quite probable that both forms of rust may occur on the same plants in the field, but both were not found.

TABLE XIII.—*Results of inoculations with urediniospores from Elymus brachystachys Scribn. and Ball.*

Place.	Date.	*Triticum vulgare.*	*Secale cereale.*
	1916.		
Minot, N. Dak.	Sept. 18	19/20	0/12

The rust on *Elymus brachystachys* was very evidently *P. graminis tritici*. From the results obtained with other species of Elymus it is very probable that *E. brachystachys* can be infected with *P. graminis secalis* also, although there is no experimental proof (Table XIII).

TABLE XIV.—*Results of inoculations with urediniospores from Elymus canadensis L.*

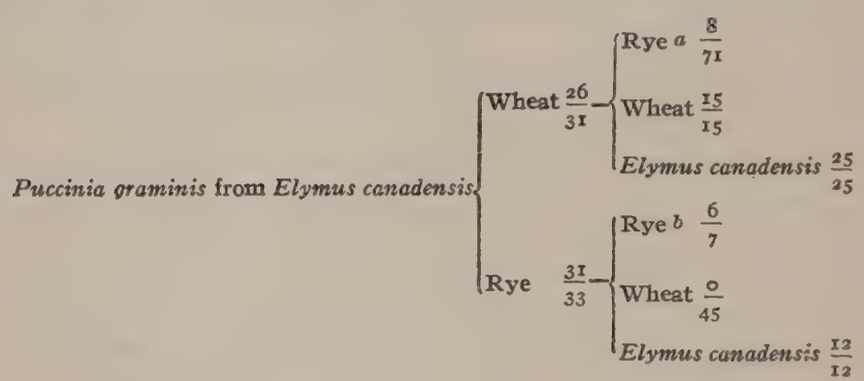
No.	Place.	Date.	*Triticum vulgare.*	*Avena sativa.*	*Hordeum vulgare.*	*Secale cereale.*	*Agropyron repens.*	*Bromus tectorum.*
		1915.						
1	St. Paul, Minn.	Aug. 19	26/31	.....	33/33	21/33	.....	.....
2	La Moure, N. Dak.	Aug. 26	9/23	0/31	7/13	8/13	.....	.....
3	Minneapolis, Minn.	Nov. 15	0/14	0/20	22/25	12/19	4/25	31/31
		1916.						
4	Brownton, Minn.	Aug. 7	27/27	.....	.....	6/24; 10	.....	.....
5	Devils Lake, N. Dak.	Sept. 15	6/15	0/16	.....	.....	20/20	.....
6	Williston, N. Dak.	Sept. 20	19/19	.....	.....	1/21; 3	.....	.....
7	Minot, N. Dak.	Sept. 21	27/27	0/24	.....	.....	.....	.....
8	Glasgow, Mont.	Sept. 22	24/24	0/23	.....	0/20; 3	.....	.....
9	Pullman, Wash.	Sept. 30	[a] 8/13	.....	.....	0/15; 5	.....	.....

[a] Wheat very distinctly hypersensitive.

Puccinia graminis tritici, *P. graminis tritici compacti*, and *P. graminis secalis* were found on *Elymus canadensis* (Table XIV). The grass is attacked with approximately equal ease by all three forms. In 1915 the wheat and rye forms were commonly found in the upper Mississippi Valley, but in 1916, a year in which there was a very severe wheat-rust epidemic, only *P. graminis tritici* was found, except in No. 4. A considerable amount of rye is grown in the region from which this particular grass material was obtained. It is interesting to note that both forms of rust were present on the rye infected in this experiment. The rust which developed in No. 4 was used in inoculating rye and wheat. On the rye 15 out of 18 leaves became infected and 7 out of 43 wheat leaves developed uredinia.

Elymus canadensis is probably not as important as some of the other grasses in stem-rust epidemiology. It may become very heavily rusted but the rust often develops late in the season, and the grass may almost entirely escape. The habit of growth may account for this fact.

DIAGRAM 5.—Results of inoculations with rust from wheat and rye recorded in No. 1, Table XIV.



[a] Very weak infection. [b] Normal infection.

Diagram 5 shows very clearly that both *P. graminis tritici* and *P. graminis secalis* were present on *E. canadensis* in No. 1. It should be remembered, of course, that *P. graminis tritici* can infect rye weakly while *P. graminis secalis* can not infect wheat.

TABLE XV.—*Results of inoculations with urediniospores from Elymus condensatus Presl.*

No.	Place.	Date.	*Triticum vulgare.*	*Avena sativa.*	*Secale cereale.*
		1916			
1	Ritzville, Wash.	Oct. 3	15/18; 3	0/16	2/14; 7
2	Ellensburg, Wash.	...do....	0/28; fl.	0/18	0/20
3	Pullman, Wash.	Oct. 5	14/17	.....	0/22; 5

Elymus condensatus was almost universally rusted both west of the Rocky Mountains and in Montana, Wyoming, and western Nebraska east of the mountains. Unfortunately no inoculations were made with the rust from east of the mountains, which would very probably have proved to be ordinary *P. graminis tritici*. All of the rust which was used in the inoculations, the results of which are recorded in Table XV, was *P. graminis tritici compacti*.

DIAGRAM 6.—Results of inoculations with urediniospores from *Elymus glaucus* Buckley.

Puccinia graminis from *Elymus glaucus* (Ellensburg, Wash.).

- Rye $\frac{1}{11}$; 7
- Wheat [a] $\frac{16}{17}$ — Barley — $\frac{21}{21}$ —
  - Barley $\frac{54}{54}$
  - Oats $\frac{0}{37}$
  - Wheat [a] $\frac{62}{68}$; 6
  - Club wheat [b] $\frac{17}{17}$

[a] Wheat very sharply hypersensitive.
[b] Heavy, normal infection on club wheat.

The character of infection on bluestem wheat, Minnesota 169, shows clearly that the rust was *P. graminis tritici compacti*. The uredinia were always small, and there were large dead spots on the leaves. On barley and club wheat, on the other hand, infection was normal.

TABLE XVI.—*Results of inoculations with urediniospores from Elymus macounii Vasey*

No.	Place.	Date.	*Triticum vulgare.*	*Avena sativa.*	*Hordeum vulgare.*	*Secale cereale.*
		1916				
1	Winnipeg, Manitoba	Aug. 24	$\frac{18}{18}$	.....	.....	$\frac{4}{38}$
2	Emerson, Manitoba	Aug. 22	$\frac{18}{22}$	$\frac{0}{19}$	$\frac{10}{10}$	$\frac{0}{13}$
3	Havre, Mont	Sept. 22	$\frac{23}{23}$	.....	.....	$\frac{3}{18}$; 4
4	Ellensburg, Wash	Oct. 5	[a] $\frac{11}{18}$; 7	.....	.....	[a] $\frac{0}{19}$; 5

[a] Wheat and rye hypersensitive.

The rust collected at Winnipeg and Emerson, Manitoba, and that collected at Havre, Montana, was all ordinary *P. graminis tritici*, while that collected at Ellensburg, Wash., was *P. graminis tritici compacti*. Both attack the grass very easily and may produce large numbers of spores on it. Although *P. graminis secalis* was not found on *Elymus macounii* in the field, it is quite possible that the grass is susceptible to this form, since the various species of Elymus seem to be quite similar in this respect (Table XVI).

TABLE XVII.—*Results of inoculations with urediniospores from Elymus robustus Scribn. and J. G. Sm.*

No.	Place.	Date.	*Triticum vulgare.*	*Avena sativa.*	*Hordeum vulgare.*	*Secale cereale.*	*Elymus canadensis.*	*Elymus robustus.*	*Hordeum jubatum.*
		1915.							
1	St. Paul, Minn.....	Aug. 11	1/11	0/33	49/54	33/40	.....	.....	.....
2	.....do.....	Sept. 2	1/21	0/29	32/32	30/30	15/15	13/13	12/12
3	.....do.....	Sept. 8	0/19	0/23	28/36	40/43	.....	13/13	.....
		1916.							
4	.....do.....	July 7	0/21	0/21	15/23	15/21	.....	.....	.....

Puccinia graminis secalis occurred on *Elymus robustus* in all four lots of material from which inoculations were made (Table XVI). A small amount of *P. graminis tritici*, however, was present on the first two lots collected. The grass is about equally susceptible to both the rye and wheat forms of stemrust, this fact being very clearly demonstrated by a great many inoculation experiments. *E. robustus*, like *E. canadensis*, may be severely rusted in the field. In the epidemic of 1916, however, it did not seem to be so universally and severely attacked as some of the species of Agropyron and *Hordeum jubatum*. Just why this was so is difficult to say. Certainly *E. robustus* is quite as susceptible as these other grasses in the greenhouse. However, on account of its habit of growth, conditions for infection may not be so favorable in the field.

TABLE XVIII.—*Results of inoculations with urediniospores from Festuca elatior L.*

No.	Place.	Date.	*Triticum vulgare.*	*Avena sativa.*	*Hordeum vulgare.*	*Phleum pratense.*
		1916.				
1	Ames, Iowa.....	July 1	.....	.....	2/20	12/30
2	Madison, Wis.[a].....	...do.....	.....	0/25	0/18	0/30
3	Bellingham, Wash.....	Sept. 7	0/27	14/31	2/28; 6	21/21
4	Sheridan, Wyo.....	Oct. 9	.....	7/26; 4	9/25; 16	.....

[a] Very few spores were viable when inoculations were made.

The rust on *Festuca elatior* was *Puccinia graminis phleipratensis* in both cases where successful infection occurred (Table XVIII). This was easily determined both by the morphology of the spores and the nature of the uredinia developed on oats and barley. The comparatively small

number of leaves of *Phleum pratense* which became infected in No. 1 was probably due to the fact that the grass inoculated had been somewhat injured by thrips. When transfers were made to healthy timothy plants, 15 out of 15 became infected.

TABLE XIX.—*Results of inoculations with urediniospores from Festuca pratensis Huds.*

No.	Place.	Date.	*Triticum vulgare.*	*Avena sativa.*	*Hordeum vulgare.*	*Secale cereale.*	*Phleum pratense.*	*Hordeum jubatum.*	*Agropyron repens.*
		1915.							
1	St. Paul, Minn.....	Aug. 10	0/26	35/47	3/18	5/37	.....	.....	.....
2	.....do.....	Aug. 10	0/25	14/22	3/27	13/26	.....	.....	.....
3	.....do.....	Aug. 16	0/54	41/65	5/40	2/44	.....	.....	.....
4	.....do.....	Sept. 2	0/22	9/38	2/11	2/12	6/8	0/5	.....
5	.....do.....	Sept. 2	0/21	6/37	7/31	4/31	9/16	1/11	0/19
		1916.							
6	Udell, Iowa.....	July 1	.....	3/67	7/31	.....	45/45	.....	.....
7	St. Paul, Minn.....	Aug. 7	0/19	15/33	3/22; 6	.....	.....	.....	.....
8	Pullman, Wash.....	Sept. 30	.....	.....	14/20; 6	.....	35/35	.....	.....

The results of the inoculations recorded in Table XIX show that the common rust on *Festuca pratensis* is *P. graminis phleipratensis* and that oats, barley, and rye may be weakly attacked. The rust did not develop well on any of the three, the uredinia always being small.

One set of inoculations was made with *P. graminis* from *Hordeum caespitosum*, collected at Coburg, Mont., on September 22, 1916. The results are given in diagram 7 and show clearly that the rust was *P. graminis tritici.*

DIAGRAM 7.—Results of inoculations with urediniospores from *Hordeum caespitosum* Scribn.

Puccinia graminis from *Hordeum caespitosum* (Coburg, Mont.) { Wheat 10/13 ; Rye 1/16

Three biologic forms of *P. graminis* were found on *Hordeum jubatum*—viz, *P. graminis tritici*, *P. graminis tritici compacti*, and *P. graminis secalis* (Table XX). Both *P. graminis tritici* and *P. graminis secalis* were isolated a number of times from the same lot of grass material. The two forms can be separated easily, as shown by diagram 8. It will be seen by referring to No. 3, Table XX, that all the inoculated leaves of barley,

TABLE XX.—*Results of inoculations with urediniospores from Hordeum jubatum L.*

No.	Place.	Date.	*Triticum vulgare.*	*Avena sativa.*	*Hordeum vulgare.*	*Secale cereale.*	*Agropyron repens.*	*Agropyron occidentale.*	*Bouteloua curtipendula.*	*Bromus tectorum.*	*Elymus canadensis.*	*Agropyron caninum.*	*Elymus robustus.*	*Elymus virginicus.*	*Hordeum jubatum.*
		1914.													
1	St. Paul, Minn.	June 25	0/24	0/29	24/29	23/23									
2	do	Sept. 8	2/30	4/30	11/30	30/30									
		1915.													
3	do	June 29	8/58		57/57	58/58					81/81		42/42	41/41	
4	do	July 14	1/47	0/56		45/48									
5	Albert Lea, Minn.	July 24	0/44		55/55	28/28									
6	St. Paul, Minn.	July 19	15/25	0/22	41/41	27/32	3/7		0/11	5/15	12/12		17/19	11/11	
7	do	July 21		0/41	48/48	24/24									
8	Jordan, Minn.	July 27	0/36	1/31	36/39	39/45									
9	St. Paul, Minn.	Aug. 5	1/36		25/25	20/20									
10	do	Aug. 5	0/40		24/24	31/35	21/23								
11	do	Aug. 10	14/72		21/38	47/50	35/36								
12	do	Aug. 16	6/42	0/30	25/25	46/49									
13	do	Aug. 16	31/36	0/37	35/35	28/33		3/3				10/10			
14	Lisbon, N. Dak.	Aug. 23	53/53	11/30	38/40	13/38	7/20								
15	do	Aug. 26	30/43	0/27	5/12	5/14									

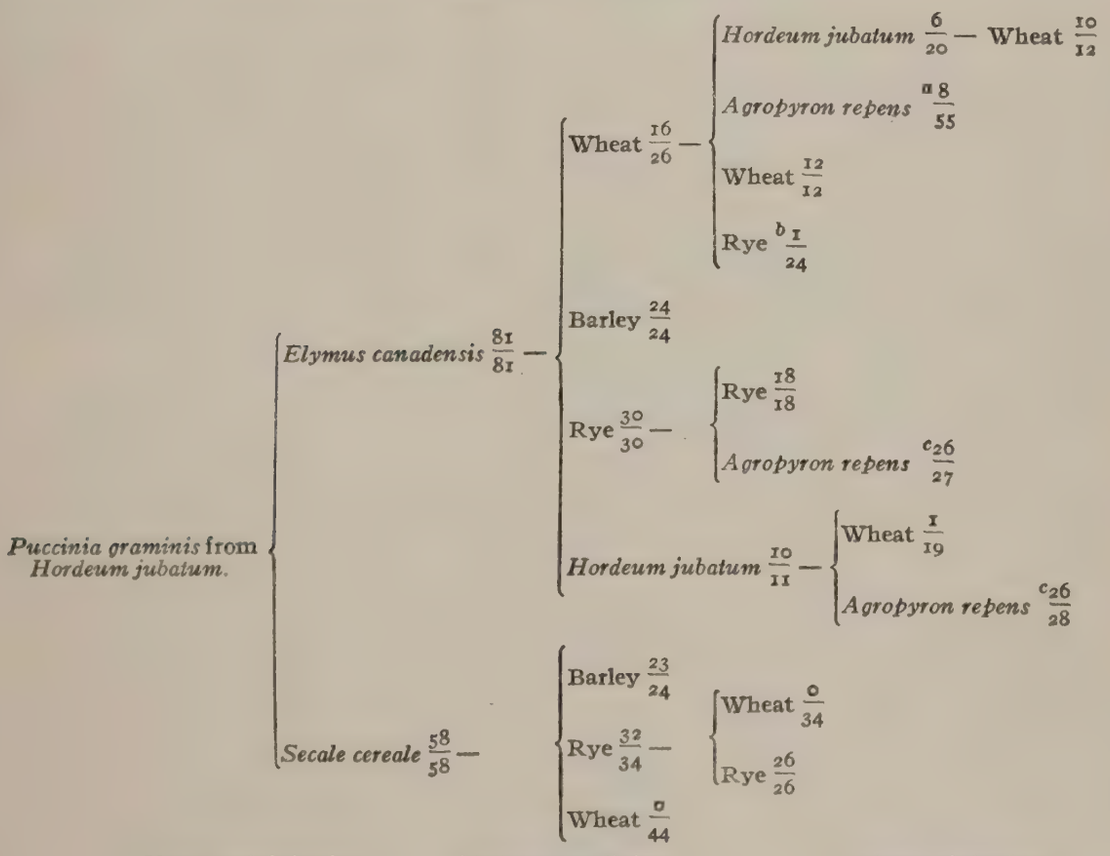
16	Dickinson, N. Dak.	Aug. 27	1/12	0/12	3/10		13/13										
17	Minot, N. Dak.	Aug. 30	24/37	2/15	17/17	16/20	9/17										
18	Harvey, N. Dak.	Aug. 31	14/23	0/13	11/15	2/15											
19	Valley City, N. Dak.	Aug. 31	5/26	0/22	13/13	3/28	2/38										
20	Jamestown, N. Dak.	Sept. 1	38/41	0/32	7/25	3/26	0/15										
21	Moorhead, Minn.	Sept. 1	10/17	0/29	27/27	22/22											
22	Madison, Wis.	Oct. 6	0/13			6/9; 2											
		1916.															
23	Onawa, Iowa	July 1			12/38	2/11											
24	McIntire, Iowa	July 8	0/3		7/11	3/10											
25	Armstrong, Iowa	July 11			1/23	0/15											
26	Madison, Wis.	July 11	0/21			10/26											
27	Hinckley, Minn.	July 31	5/24			4/17; 3											
28	Denver, Colo.	Aug. 5	1/15			0/15											
29	Watertown, S. Dak.	Aug. 5	12/36			0/32											
30	Brownton, Minn.	Aug. 7	6/9			0/13; 1											
31	Two Harbors, Minn.	Aug. 14	7/24			24/25											
32	Grand Rapids, Minn.	Aug. 15	36/38		6/15	6/29; 6											
33	Emerson, Manitoba	Aug. 21	50/50			2/22											
34	Hawley, Minn.	Aug. 19	0/40	0/41	2/18	0/34											

TABLE XX.—*Results of inoculations with urediniospores from Hordeum jubatum L.*—Continued

No.	Place.	Date.	*Triticum vulgare.*	*Avena sativa.*	*Hordeum vulgare.*	*Secale cereale.*	*Agropyron repens.*	*Agropyron occidentale.*	*Bouteloua curtipendula.*	*Bromus tectorum.*	*Elymus canadensis.*	*Agropyron caninum.*	*Elymus robustus.*	*Elymus virginicus.*	*Hordeum jubatum.*
		1916.													
35	Crookston, Minn	Aug. 21	30/30			6/19									
36	Portage la Prairie, Manitoba	Aug. 24	14/14			2/16									
37	Devils Lake, N. Dak	Sept. 15	7/17	0/16			25/29								
38	Berwick, N. Dak	Sept. 15		0/13	18/18		18/37								
39	Churchs Ferry, N. Dak	Sept. 20	13/14			1/20; 3									
40	Minot, N. Dak	Sept. 18	9/14	0/15		0/14; 7									
41	Williston, N. Dak	Sept. 22	17/17	0/17		1/18									
42	Cut Bank, Mont	Sept. 22	19/19			0/19									
43	Havre, Mont	Sept. 20	16/16	0/20		5/19; 3									
44	Pullman, Wash	Oct. 24	16/40; 12		50/53	1/32; 7									9/20
45	Glasgow, Mont	Sept. 30	15/15			1/13; 2									
46	Sheridan, Wyo	Oct. 9	10/15			1/22; 1									
47	Newcastle, Wyo	Oct. 7	12/12			0/7; 2									
48	Crawford, Nebr	Oct. 9	15/15			2/20; 15									
49	.....do	Oct. 12	12/12	0/18		1/11									

rye, and the three species of Elymus became infected, while only a small percentage of the wheat leaves developed uredinia. Barley and the three grasses were known to be congenial hosts for both forms of the stemrust. It was therefore to be expected that each was infected with the two. This proved to be the case, but evidently more of the rye form was present than of the wheat form, as would also be supposed from the results in No. 3. This is shown in the diagram by the fact that not all of the inoculated wheat leaves rusted, while all of the rye leaves did. The weak infection which resulted on *Agropyron repens* and rye from the inoculation with the rust developed on wheat showed that the wheat developed only the wheat form, while the rye very clearly developed only the rye form.

DIAGRAM 8.—Results of inoculations with urediniospores developed on *Elymus canadensis* and *Secale cereale* in No. 3, Table XX.

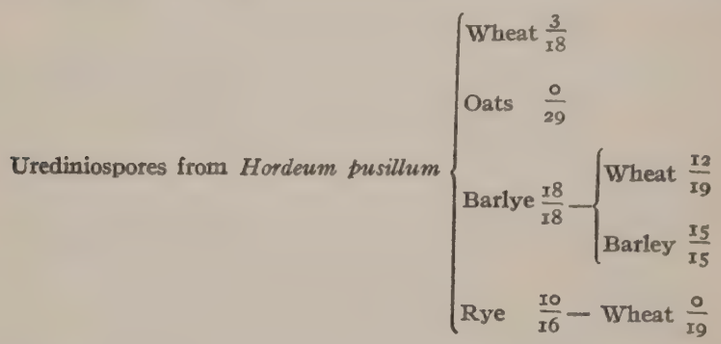


[a] Very weak infection. [b] Minute uredinium. [c] Very heavy infection.

In 1916 very little of the *secalis* form developed. The rust developed on rye in No. 31 was of this form. Except for this one lot of material, however, little or none of the *secalis* form was found during the summer. The uredinia developed on rye in the other trials were small and the flecks sharp, indicating the presence of *P. graminis tritici*. Inoculations from rye to wheat and rye also showed this to be true. *P. graminis tritici compacti* was found on *Hordeum jubatum* only at Pullman, Wash., west of the Rocky Mountains. The rusts east of the mountains were practically the same, although there sometimes appeared to be slight differences in virulence.

Probably no grass is responsible for spreading more wheat stemrust than *Hordeum jubatum*. It rusts early in the season, especially near barberries, and during a season favorable to rust development it becomes almost universally rusted. In amount of rust developed it is approached probably only by *Agropyron repens*, which, however, is host for *P. graminis secalis*, not *P. graminis tritici*. Inconceivably large numbers of urediniospores are developed by these grasses, and when the rusted grass is disturbed on windy days clouds of spores, which are probably carried considerable distances by the wind, can easily be seen.

DIAGRAM 9.—Results of inoculations with urediniospores from *Hordeum pusillum Nutt.*



The rust was collected in the grass garden on University Farm, St. Paul, Minn., and inoculations were made on August 30, 1916. Both the wheat and rye forms were present (see diagram 9).

TABLE XXI.—*Results of inoculations with urediniospores from Hordeum vulgare*

No.	Place.	Date.	*Triticum vulgare.*	*Avena sativa.*	*Hordeum vulgare.*	*Secale cereale.*
		1915.				
1	St. Paul, Minn.	July 17	8/9	.....	.....	.....
2	Ramsey Co., Minn.	...do.....	3/6	.....	.....	0/12
3	.....do.....	Oct. 14	29/31	0/16	14/15	1/29
		1916.				
4	Hinckley, Minn.[a]	July 29	2/20	.....	.....	1/15
5	Pine City, Minn.[a]	Aug. 1	4/15	.....	.....	0/10; 5
6	Emerson, Manitoba	Aug. 22	26/31	0/23	10/11	2/15; 4
7	Portage la Prairie, Manitoba[b]	Aug. 24	10/10	.....	.....	2/19
8	Williston, N. Dak.	Sept. 20	18/18	.....	.....	4/15; 3

[a] Greenhouse conditions unfavorable for infection.
[b] Hooded barley.

The work with barley was done particularly to determine whether a special biologic form occurs on barley (Table XXI). Freeman and Johnson (14, p. 19) obtained results which led them to believe this to be the case. The form on barley in their experiments seemed to infect rye and oats more readily than either the wheat stemrust form or the rye form. They therefore named the barley form *P. graminis hordei* F. and J. (14, p. 27). It will be seen from Table XXI that all of the rust collected on barley in the field by the writers was ordinary *P. graminis tritici*. Only two sets of inoculations were made on oats, but successful infection did not occur in either. However, Derr (14, p. 18) successfully infected oats with *P. graminis tritici* taken directly from wheat. Freeman and Johnson (14, p. 20) also succeeded in infecting rye more easily with barley rust than with wheat rust. However, the writers obtained, in a number of sets of inoculations, a greater percentage of infection on rye with *P. graminis tritici* than Freeman and Johnson report having obtained with *P. graminis hordei*. The percentage of leaves of rye which become infected when inoculated with the same strain of *P. graminis tritici* and the degree of infection both vary greatly in different trials.

Further, barley can be infected by all of the common biologic forms of *P. graminis*, and the possibilities for mixed strains on this host are therefore not to be overlooked. It is unquestionably a very congenial host for *P. graminis secalis*, *P. graminis tritici*, and *P. graminis tritici compacti* and can be quite consistently weakly infected by *P. graminis avenae*, *P. graminis agrostis*, and *P. graminis phleipratensis*. It is unquestionably the least specialized of any of the cereals toward *P. graminis*.

It is doubtful, therefore, whether there is a separate biologic form for barley.

TABLE XXII.—*Results of inoculations with urediniospores from Hystrix patula Moench*

No.	Place.	Date.	*Triticum vulgare.*	*Avena sativa.*	*Hordeum vulgare.*	*Secale cereale.*	*Hordeum jubatum.*	*Agropyron caninum.*
		1915.						
1	St. Paul, Minn.	Aug. 10	4/46	0/13	61/68	31/33	.....	.....
2	.....do.....	Sept. 2	4/30	0/29	25/26	21/22	6/6	8/10
3	Ransey County, Minn.	...do.....	.....	.....	12/15	.....	.....	.....

Both *P. graminis tritici* and *P. graminis secalis* may occur on *Hystrix patula* (Table XXII). The *P. graminis secalis*, however, which was isolated from the grass differed somewhat from ordinary strains of this biologic form. The urediniospores are smaller, and the rust is less virulent on the cereals than *P. graminis secalis*. This is especially true of

barley. On this host the rust develops only weakly, while *P. graminis secalis* develops normally. On some of the grasses susceptible to *P. graminis secalis*, however, the *Hystrix patula* strain develops normally. It can very easily infect and develop normally on *Agropyron repens*, *A. tenerum*, *A. caninum*, *Elymus virginicus*, *Hordeum jubatum*, and *Hystrix patula*. While there may be sufficient reason for considering this a separate biologic form, it is probably preferable to consider it only a variant form of *P. graminis secalis* without giving it a new name.

TABLE XXIII.—*Results of inoculations with urediniospores from Koeleria cristata (L.) Pers.*

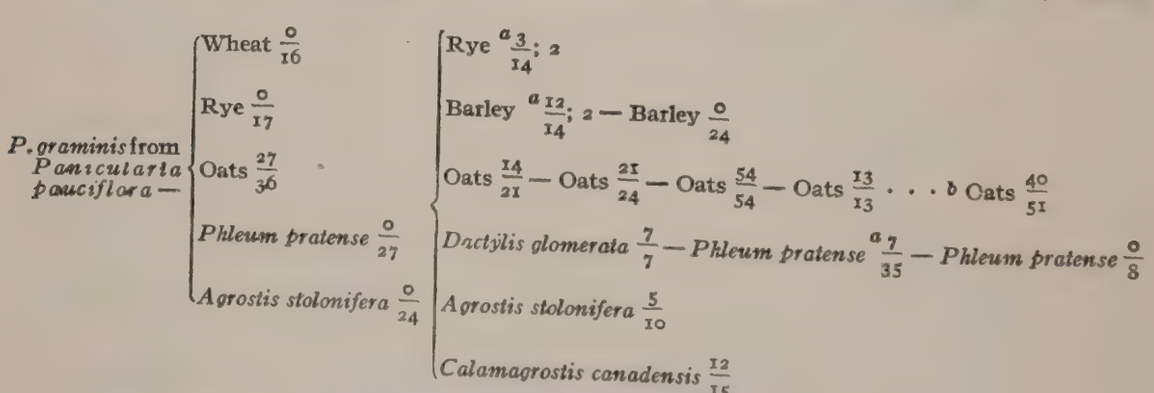
No.	Place.	Date.	*Triticum vulgare.*	*Avena sativa.*	*Hordeum vulgare.*	*Secale cereale.*
		1915				
1	St. Paul, Minn.[a]	May 14	.....	$\frac{5}{6}$	.....	.....
2	.....do.....	May 22	$\frac{0}{17}$	.....	$\frac{0}{18}$	$\frac{0}{7}$
		1916				
3	Manhattan, Kan.[b]	June 5	.....	$\frac{1}{43}$	$\frac{11}{40}$	.....

[a] Grass planted in greenhouse in fall. [b] Material badly dried.

The rust developed in No. 1 (Table XXIII) was undoubtedly *P. graminis avenae*, while that in No. 3 was very probably *P. graminis phleipratensis*. A large number of inoculations were made on the grass with the stemrust of oats, as well as with the other forms of stemrust. The results showed clearly that *Koeleria cristata* is very susceptible to *P. graminis avenae*, *P. graminis agrostis*, and *P. graminis phleipratensis*, but not to *P. graminis secalis*, *P. graminis tritici*, or *P. graminis tritici compacti*.

Panicularia pauciflora was very heavily and commonly rusted in the mountain valleys just west of the Continental Divide in Montana. The rust proved to be ordinary *P. graminis avenae* (diagram 10). The char-

DIAGRAM 10.—Results of inoculations with urediniospores from *Panicularia pauciflora* (Presl.) Kuntze.


P. graminis from Panicularia pauciflora —
Wheat 0/16
Rye 0/17
Oats 27/36
Phleum pratense 0/27
Agrostis stolonifera 0/24
Rye [a]3/14; 2
Barley [a]12/14; 2 — Barley 0/24
Oats 14/21 — Oats 21/24 — Oats 54/54 — Oats 13/13 . . . [b] Oats 40/51
Dactylis glomerata 7/7 — Phleum pratense [a]7/35 — Phleum pratense 0/8
Agrostis stolonifera 5/10
Calamagrostis canadensis 12/15

[a] Minute uredinia. [b] Dots indicate that a number of intervening transfers were made.

acter of infection on the cereals and grasses was the same as that produced by the other strains of *P. graminis avenae* which were tried. The rust developed normally on oats and *Dactylis glomerata*, nearly normally on *Calamagrostis canadensis*, and but very imperfectly on barley, rye, and *Phleum pratense*.

TABLE XXIV.—*Results of inoculations with urediniospores from Phleum pratense L.*

No.	Place.	Date.	*Triticum vulgare.*	*Avena sativa.*	*Hordeum vulgare.*	*Secale cereale.*	*Agrostis alba.*	*Dactylis glomerata.*	*Phleum pratense.*
		1915.							
1	St. Paul, Minn....	Aug. 17	0/44	30/35	18/46	2/45	.....	.....	30/30
2	.....do.....	Aug. 26	0/44	7/21	9/21	2/26	.....	14/15	2/2
3	.....do.....	Aug. 26	0/38	8/34	4/27	2/36	.....	10/10	9/9
4	.....do.....	Sept. 4	0/31	8/27	2/29	0/17	.....	.....	.....
		1916.							
5	Denver, Colo.....	Mar. 16	.....	.....	.....	.....	.....	.....	25/25
6	.....do.....	Mar. 30	.....	.....	.....	.....	0/9	.....	.....
7	Madison, Wis.....	May 3	.....	.....	1/77	.....	.....	.....	.....
8	Seward, Nebr.....	June 2	.....	.....	9/39	.....	.....	.....	.....
9	Denver, Colo.....	June 20	.....	0/18	24/70	1/15	.....	.....	25/25
10	Worthington, Minn	July 2	.....	.....	0/19	.....	.....	.....	.....
11	Ames, Iowa.....	July 3	.....	.....	9/28	.....	.....	.....	.....
12	Centerville, Iowa..	July 3	.....	.....	10/27	.....	.....	.....	.....
13	Carroll, Iowa.....	July 3	.....	.....	10/40	.....	.....	.....	.....
14	Armstrong, Iowa..	July 11	.....	.....	0/20	.....	.....	.....	.....
15	Long Beach, Cal..	July 11	.....	1/27	0/32	.....	.....	.....	.....
16	Castlewood, S. Dak	Aug. 5	.....	.....	0/17	.....	.....	.....	.....
17	Brookings, S. Dak.	Aug. 5	.....	.....	0/46	.....	.....	.....	4/14
18	Grand Rapids Minn.....	Aug. 15	.....	.....	9/48	.....	.....	.....	15/15
19	Hawley, Minn.....	Aug. 19	.....	.....	0/33	.....	.....	.....	1/15
20	Emerson, Manitoba	Aug. 21	.....	.....	10/37	.....	.....	.....	40/40

TABLE XXIV.—*Results of inoculations with urediniospores from Phleum pratense L.*—Continued

No.	Place.	Date.	*Triticum vulgare.*	*Avena sativa.*	*Hordeum vulgare.*	*Secale cereale.*	*Agrostis alba.*	*Dactylis glomerata.*	*Phleum pratense.*
21	Portage la Prairie, Manitoba.....	1916. Aug. 23	.....	.....	$\frac{10}{43}$	.....	.....	.....	$\frac{14}{14}$
22	Winnipeg, Manitoba.....	Aug. 23	.....	.....	$\frac{2}{18}$	.....	.....	.....	$\frac{18}{18}$
23	Whitefish, Mont...	Sept. 30	.....	.....	$\frac{4}{16}$; 10	.....	.....	.....	.....
24	Ponderay, Idaho..	Sept. 30	.....	.....	$\frac{12}{16}$; 3	.....	.....	.....	.....
25	Pullman, Wash...	Sept. 30	.....	.....	$\frac{7}{13}$; 3	.....	.....	.....	$\frac{21}{21}$
26	Ellensburg, Wash..	Oct. 3	.....	.....	$\frac{18}{31}$; 11	.....	.....	.....	.....
27	Sheridan, Wyo....	Oct. 7	.....	.....	$\frac{6}{15}$; 8	.....	.....	.....	.....
28	Newcastle, Wyo...	Oct. 7	.....	.....	$\frac{7}{14}$; 5	.....	.....	.....	.....
29	Crawford, Nebr...	Oct. 9	.....	.....	$\frac{10}{44}$; 13	$\frac{1}{1}$	.....	.....	.....

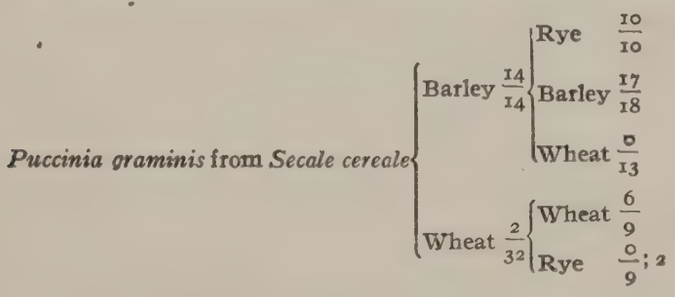
The work with timothy rust had two main objects: (1) To determine whether *Puccinia graminis phleipratensis* varied greatly in different regions, and (2) to ascertain whether the rust could be easily changed. The reason for the investigation was the fact that, whereas previous investigators were unable to infect barley with the rust, Stakman and Jensen (26) found no particular difficulty in doing so, thus suggesting either different strains of the rust in nature, or an ability of the rust to change rapidly. The attempts to increase the virulence of the rust will be discussed in a subsequent paper; the results of the direct inoculations are given in Table XXIV. There was little if any real difference between strains. The rust failed to infect barley in only a few cases. These failures, however, are not surprising, since conditions varied considerably in the different trials. Variable results are often obtained when the same strain of rust is used. It will be noticed that successful infection did not occur to any extent in No. 14, 15, 16, and 17. The reason for this is very probably the fact that the weather was extremely hot during this period. The subsequent inoculations, with one exception, were successful. The percentages of successful infection were especially high in late September and early October, a period during which weather conditions were ideal for rust development in the greenhouse. All rusts developed unusually well during this period, while during the extremely hot weather in July and early August none developed very well.

TABLE XXV.—*Results of inoculations with urediniospores from Secale cereale L.*

No.	Place.	Date.	*Triticum vulgare.*	*Avena sativa.*	*Hordeum vulgare.*	*Secale cereale.*	*Elymus virginicus.*	*Bromus tectorum.*
		1914.						
1	St. Paul, Minn.....	June 9	0/22	0/19	13/20	16/18	.....	.....
2	.....do.....	June 16	0/20	0/27	12/17	17/18	.....	.....
3	.....do.....	June 25	0/10	.....	.....	.....	.....	.....
		1915.						
4	Ramsey Co., Minn.....	June 17	4/21	1/41	42/44	11/12	35/40	.....
5	.....do.....	June 22	1/35	[a] 2/43	48/48	31/34	12/12	0/23
		1916.						
6	Portage la Prairie, Manitoba.	Aug. 24	2/32	.....	14/14	.....	.....	.....

[a] Minute uredinia.

DIAGRAM 11.—Results of inoculations with rust developed in No. 6, Table XXV.

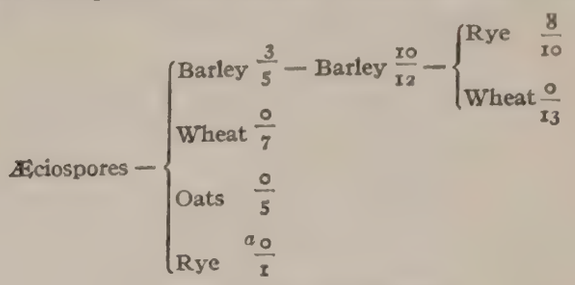


Rye is usually affected with *P. graminis secalis* in the field. It will be noticed that the rust infects barley very readily and can infect oats only occasionally and with difficulty. The uredinia on oats were all very small. *P. graminis tritici* may also occur rarely on rye. The fact that the wheat stemrust and not the rye stemrust infected wheat in No. 6 in Table XXV is shown in diagram 11. The rust on barley was all the rye form, since it could not infect wheat. The rust on the wheat, however, was clearly *P. graminis tritici*, since it infected wheat but produced only two flecks on rye. The very limited infection of rye by wheat stemrust in the field is probably of little practical consequence.

The inoculations reported in diagram 12 were made with æciospores developed on *Berberis vulgaris* as a result of inoculations with teliospore material which was sent by Dr. J. C. Arthur, of Purdue University. It could be seen that the rust was unquestionably *P. graminis secalis*. The reason for the failure on the one rye leaf inoculated directly with æciospores was that this leaf died early, thus making the trial inconclusive. However, the subsequent infection on rye as a result of inoculations

from *B. vulgaris* was very severe, clearly establishing the identity of the rust.

DIAGRAM 12.—Results of inoculations with æciospores developed on *Berberis vulgaris* from inoculations with teliospores from *Sporobolus cryptandrus* (Torr.) Gray.



[a] Leaves died early; inconclusive.

TABLE XXVI.—*Results of inoculations with urediniospores from Triticum compactum Host*

No.	Place.	Date.	*Triticum vulgare.*	*Avena sativa.*	*Hordeum vulgare.*	*Secale cereale.*	*Agropyron tenerum.*
1	Pullman, Wash.[a].....	1916. Oct. 21	[b] 5/31; 1	.....	[c] 7/25	0/25	[c] 7/48

[a] Old spore material; many spores probably not viable.
[b] Hypersensitive.
[c] Normal infection.

The low percentage of infection from *Triticum compactum* is probably due to the fact that inoculations were made about a month after the rust was collected, and many of the spores had very probably lost their viability (Table XXVI).

It is not known whether all of the rust on club wheat west of the Rocky Mountains is of this type, since it is also susceptible to ordinary *P. graminis tritici;* but, on account of the absence of ordinary *P. graminis tritici* from grasses on which it would be expected to occur and on account of the prevalence of the club-wheat form on those grasses, it is probable that by far the greatest amount of rust on club wheat west of the mountains is *P. graminis tritici compacti.*

Only a few inoculations were made directly from wheat. These represent only a very small proportion of the total number of inoculations made with *P. graminis tritici.* Further inoculations were made with the rust, developed as a result of the inoculations reported in Table XXVII, but the results were of no particular interest, since they did not differ from any of those previously obtained.

It is quite apparent that in the upper Mississippi Valley and northern Great Plains area there are at least five biologic forms of *Puccinia graminis,* if *P. phleipratensis* be considered a biologic form, which seems quite justifiable—viz, *P. graminis tritici, P. graminis secalis, P. graminis avenae, P. graminis agrostis,* and *P. graminis phleipratensis.* In addition to these may be mentioned the strain *P. graminis secalis* found on *Hystrix patula.* There is probably not sufficient reason for calling this

a distinct biologic form, although it is somewhat different from any other form studied.

TABLE XXVII.—*Results of inoculations with urediniospores from Triticum vulgare*

No.	Place.	Date.	*Triticum vulgare.*	*Hordeum vulgare.*	*Secale cereale.*	*Agropyron repens.*	*Elymus virginicus.*	*Elymus robustus.*
		1915.						
1	St. Paul, Minn.....	May 22	.....	33/35	2/34	.....	23/26	31/32
		1916.						
2	Manhattan, Kans.....	June 3	44/53	11/12	2/16	.....	.....	.....
3	Denver, Colo.....	Aug. 5	9/16	.....	0/19	0/9	.....	.....
		1917.						
4	Leederville, West Australia [a].....	Feb. 7	[b] 6/11	13/14	0/6; 1	.....	.....	.....

[a] One generation on club wheat in greenhouse before inoculations were made.
[b] Normal infection.

In the Palouse country of Washington and Idaho there is a common form resembling *P. graminis tritici* in many respects, but still very distinct from it. There seems sufficient reason for considering this a distinct biologic form for which the name "*Puccinia graminis tritici compacti*" is suggested.

Except for the variations mentioned, all of the rusts collected could be referred to one of the ordinary biologic forms, although there were sometimes slight differences in virulence. In general, however, the results of inoculations with different strains of a biologic form were monotonously uniform.

The results show very clearly, however, that the forms of stemrust which attack cereals commonly occur on many wild grasses over a large area.

After the identity of the different strains of biologic forms isolated from grasses or cereals from the field had been established inoculations were made on cereals and grasses, in order to determine whether the behavior was always constant.

KEY TO TABLES XXVIII–XXXIII

In Table XXVIII, and those following, "Original host" refers to the host on which the rust was collected in the field; "Immediate host" refers to the host from which spores were taken for inoculation; "Trials" refers to the number of different sets of inoculations made, plus (+) indicating the number of trials in which some plants became infected and minus (−) the number of entirely unsuccessful trials. The results are given in the form of a fraction, the denominator denoting the total number of leaves inoculated in all trials and the numerator the number which became infected.

TABLE XXVIII.—*Results of inoculations with urediniospores of Puccinia graminis tritici*

Original host.	Immediate host.	Plant inoculated.	Trials.		Result.	Degree of infection.
			+	−		
Triticum vulgare	*Triticum vulgare*	*Agropyron caninum*	2	0	3/75	Moderate.
Hordeum jubatum	*Hordeum vulgare*	do	0	2	0/70	
Do	*Triticum vulgare*	do	0	1	0/12	
Agropyron tenerum	*Hordeum vulgare*	*Agropyron cristatum*	0	1	0/6	
Hordeum jubatum	do	do	2	1	9/53	Do.
Do	do	*Agropyron desertorum*	0	2	0/33	
Do	do	*Agropyron elongatum*	1	0	15/18	Do.
Agropyron tenerum	do	*Agropyron imbricatum*	0	1	0/24	
Hordeum jubatum	*Agropyron tenerum*	do	0	1	0/3	
Do	*Hordeum vulgare*	do	0	1	0/31	
Do	do	*Agropyron intermedium*	1	1	2/26	Weak to moderate.
Agropyron smithii	do	do	1	0	1/27	Weak.
Hordeum jubatum	do	*Agropyron repens*	14	3	81/465	Do.
Do	*Triticum vulgare*	do	1	1	9/47	Do.
Agropyron smithii	*Hordeum vulgare*	do	3	2	14/141	Do.
Agropyron tenerum	do	do	2	1	6/84	Do.
Do	*Elymus virginicus*	do	1	0	1/31	Do.
Agropyron smithii	*Hordeum jubatum*	do	0	1	0/22	
Agropyron cristatum	*Hordeum vulgare*	do	2	0	14/107	Do.
Hordeum jubatum	*Agropyron smithii*	do	2	0	4/48	Do.
Agropyron cristatum	*Agropyron tenerum*	do	1	0	2/14	Do.
Do	*Hordeum vulgare*	do	1	0	1/14	Do.
Hordeum jubatum	*Agropyron repens*	do	2	0	8/38	Do.
Agropyron tenerum	*Agropyron smithii*	do	1	0	1/30	Do.
Hordeum jubatum	do	*Agropyron sibericum*	0	1	0/14	
Do	*Hordeum vulgare*	do	0	1	0/20	
Do	*Agropyron tenerum*	do	0	1	0/3	
Do	*Hordeum vulgare*	*Agropyron smithii*	6	0	47/140	Moderate to heavy.

TABLE XXVIII.—*Results of inoculations with urediniospores of Puccinia graminis tritici*—Continued

Original host.	Immediate host.	Plant inoculated.	Trials. +	Trials. −	Result.	Degree of infection.
Agropyron smithii	*Hordeum vulgare*	*Agropyron smithii*	2	0	10/13	Heavy.
Agropyron cristatum	do	do	1	0	3/5	Do.
Hordeum jubatum	do	*Agropyron tenerum*	4	2	113/221	Moderate to heavy.
Do	*Triticum vulgare*	do	3	1	170/185	Heavy.
Agropyron tenerum	*Hordeum vulgare*	do	2	0	44/44	Do.
Do	*Elymus virginicus*	do	1	0	16/16	Do.
Agropyron smithii	*Hordeum vulgare*	do	2	0	67/67	Do.
Agropyron cristatum	do	do	2	0	49/49	Do.
Hordeum jubatum	do	*Agrostis alba*	0	1	0/150	
Agropyron smithii	*Hordeum jubatum*	do	0	1	0/70	
Triticum vulgare	*Triticum vulgare*	do	0	1	0/40	
Hordeum jubatum	*Hordeum vulgare*	*Agrostis stolonifera*	0	1	0/16	
Triticum vulgare	*Triticum vulgare*	do	0	1	0/68	
Hordeum jubatum	*Hordeum vulgare*	*Alopecurus geniculatus*	0	1	0/24	
Do	do	*Alopecurus pratensis*	1	1	3/130	Weak.
Agropyron tenerum	do	do	1	0	3/38	Do.
Triticum vulgare	*Triticum vulgare*	do	0	1	0/40	
Do	do	*Anthoxanthum odoratum*	0	1	0/60	
Hordeum jubatum	*Hordeum vulgare*	*Avena sativa*	5	6	8/372	Do.
Do	*Triticum vulgare*	do	1	2	2/111	Do.
Do	*Bromus tectorum*	do	0	3	0/54	
Agropyron smithii	*Hordeum vulgare*	do	0	2	0/26	
Agropyron tenerum	do	do	0	2	0/64	Do.
Triticum vulgare	*Triticum vulgare*	do	1	2	1/113	
Hordeum jubatum	*Hordeum vulgare*	*Beckmannia erucaeformis*	0	1	0/10	
Do	do	*Bouteloua curtipendula*	0	1	0/14	
Do	*Triticum vulgare*	*Bromus erectus*	0	1	0/9	
Do	*Hordeum vulgare*	do	0	1	0/17	

TABLE XXVIII.—*Results of inoculations with urediniospores of Puccinia graminis tritici*—Continued

Original host.	Immediate host.	Plant inoculated.	Trials.		Result.	Degree of infection.
			+	−		
Hordeum jubatum	*Triticum vulgare*	*Bromus hordeaceus*	1	0	2/17	Weak.
Agropyron tenerum	*Bromus tectorum*	do	0	1	0/8	
Hordeum jubatum	*Agropyron tenerum*	do	1	0	6/18	Moderate.
Do	*Triticum vulgare*	*Bromus inermis*	0	2	0/48	
Agropyron tenerum	*Hordeum vulgare*	*Bromus pumila*	1	0	14/16	Weak.
Hordeum jubatum	do	do	1	0	8/26	Do.
Do	do	*Bromus tectorum*	3	0	123/168	Light.
Do	*Triticum vulgare*	do	1	0	70/70	Do.
Agropyron tenerum	*Hordeum vulgare*	do	1	0	39/39	Do.
Hordeum jubatum	*Bromus tectorum*	do	1	0	18/25	Do.
Agropyron tenerum	do	do	2	0	25/36	Do.
Agropyron smithii	*Hordeum vulgare*	do	2	0	17/25	Weak.
Do	*Bromus tectorum*	do	0	1	0/5	
Hordeum jubatum	*Hordeum vulgare*	*Calamagrostis canadensis*	0	1	0/12	
Triticum vulgare	*Triticum vulgare*	*Cynodon dactylon*	0	1	0/4	
Hordeum jubatum	*Hordeum vulgare*	*Cynosurus cristatus*	0	1	0/22	
Do	do	*Dactylis glomerata*	1	1	1/60	Do.
Do	*Bromus tectorum*	do	1	0	1/15	Do.
Do	*Triticum vulgare*	*Elymus canadensis*	1	0	28/28	Heavy.
Do	*Hordeum vulgare*	do	2	0	33/43	Do.
Do	*Elymus canadensis*	do	2	0	98/98	Do.
Elymus canadensis	*Triticum vulgare*	do	1	0	25/25	Do.
Agropyron smithii	do	do	1	0	44/44	Do.
Triticum vulgare	do	*Elymus robustus*	1	0	31/32	Do.
Do	*Elymus robustus*	do	2	0	57/62	Do.
Hordeum jubatum	*Hordeum vulgare*	do	4	0	84/100	Do.
Do	*Triticum vulgare*	*Elymus virginicus*	1	0	30/34	Do.
Do	*Hordeum vulgare*	do	3	0	29/60	Moderate to heavy.

TABLE XXVIII.—*Results of inoculations with urediniospores of Puccinia graminis tritici*—Continued

Original host.	Immediate host.	Plant inoculated.	Trials. +	Trials. −	Result.	Degree of infection.
Agropyron tenerum	*Hordeum vulgare*	*Elymus virginicus*	1	0	35/35	Heavy.
Agropyron smithii	do	do	1	0	32/32	Do.
Hordeum jubatum	do	*Festuca ovina*	0	1	0/20	
Do	do	*Festuca rubra*	0	1	0/31	
Triticum vulgare	*Triticum vulgare*	*Holcus lanatus*	0	1	0/44	
Hordeum jubatum	*Hordeum vulgare*	*Hordeum jubatum*	2	0	14/20	Do.
Do	*Elymus canadensis*	do	1	0	10/11	Do.
Do	*Triticum vulgare*	do	1	0	6/20	Do.
Agropyron tenerum	*Hordeum vulgare*	do	1	0	33/33	Do
Agropyron smithii	do	do	2	0	76/76	Do.
Hordeum jubatum	do	*Hordeum pusillum*	2	0	80/80	Do.
Agropyron tenerum	do	do	1	0	14/14	Do.
Hordeum jubatum	do	*Hordeum spontaneum*	1	0	8/10	Moderate.
Various	Various	*Hordeum vulgare*	X	0	4296/4503	Heavy.
Hordeum jubatum	*Hordeum vulgare*	*Hordeum vulgare* (Abyssinian).	3	0	60/75	Moderate.
Do	do	*Hordeum vulgare pallidum.*	1	0	25/27	Do.
Do	do	*Hordeum vulgare pallidum* subvar. *pyramidatum.*	1	0	11/32	Do.
Do	do	*Hystrix patula*	1	0	8/37	Do.
Agropyron tenerum	do	do	1	0	9/18	Do.
Hordeum jubatum	*Triticum vulgare*	*Koeleria cristata*	0	1	0/45	
Do	do	*Lolium italicum*	0	1	0/24	
Do	do	*Lolium perenne*	0	1	0/24	
Do	do	*Lolium temulentum*	0	1	0/23	
Do	*Hordeum vulgare*	*Poa nemoralis*	0	1	0/45	
Do	do	Secale cereale [a]	12	10	62/795	Weak.
Do	*Triticum vulgare*	do	2	0	9/120	Do.
Do	*Secale cereale*	do	5	6	12/91	Do.
Do	*Hordeum vulgare*	*Triticum compactum*	1	0	14/14	Heavy.

[a] The results recorded for *Secale cereale* represent only a small percentage of the total number of inoculations. These results will be given in another paper.

TABLE XXVIII.—*Results of inoculations with urediniospores of Puccinia graminis tritici*—Continued

Original host.	Immediate host.	Plant inoculated.	Trials. +	Trials. −	Result.	Degree of infection.
Triticum vulgare.....	*Triticum vulgare*.....	*Triticum compactum*...	2	0	34/40	Heavy.
Do.....	do.....	*Triticum dicoccum*.....	2	0	10/30	Weak.
Hordeum jubatum.....	*Hordeum vulgare*.....	.....do.....	1	0	3/4	Do.
Do.....	.....do.....	*Triticum durum*.....	4	0	14/14	Varies with variety.
Triticum vulgare.....	*Triticum vulgare*.....	.....do.....	3	0	27/44	Do.
Do.....	.....do.....	*Triticum monococcum*..	0	1	0/5	
Hordeum jubatum.....	*Hordeum vulgare*.....	.....do.....	1	0	2/6	Weak.
Do.....	.....do.....	*Triticum polonicum*....	1	0	3/3	Heavy.
Do.....	.....do.....	*Triticum speltum*.....	1	0	9/16	Weak.
Do.....	.....do.....	*Triticum turgidum*.....	1	0	6/7	Moderate.
Do.....	.....do.....	*Triticum vulgare* [a].....	X	0	100 per cent.	Heavy.

[a] A very large number of inoculations were made with many wheat rust strains. Nearly always 100 per cent of the leaves became heavily infected.

The following summary can be made from the results obtained. The results of inoculations with rust from the various species of Triticum listed below are not given in the tables, since the results were so obviously what would be expected, and in one or two cases the inoculations were not actually made.

Hosts found infected in nature: *Agropyron caninum* (L.) Beauv., *A. cristatum* J. Gaert., *A. smithii* Rydb., *A. spicatum* (Pursh,) Rydb., *A. tenerum* Vasey, *Elymus brachystachys* Scribn. and Ball, *E. canadensis* L., *E. macounii* Vasey, *E. robustus* Scribn. and J. G. Sm., *E. virginicus* L., *Hordeum caespitosum* Scribn., *H. jubatum* L., *H. pusillum* Nutt., *H. vulgare* L., *Hystrix patula* Moench., *Secale cereale* L., *Triticum compactum* Host., *T. dicoccum* Schr., *T. durum* Desf., *T. monococcum* L., *T. polonicum* L., *T. spelta* L., *T. turgidum* L., *T. vulgare* Vill.

Hosts easily infected artificially: *Agropyron elongatum* Host., *Bromus hordeaceus* L., *B. pumila*, *B. tectorum* L., *Hordeum spontaneum* K. Koch., *H. vulgare* (Abyssinian), *H. vulgare pallidum* Ser., *H. vulgare pallidum* subvar. *pyramidatum*.

Weakly infected as a result of artificial inoculation: *Agropyron intermedium* Beauv., *A. repens* (L.) Beauv., *Alopecurus pratensis* L., *Avena sativa* L., *Secale cereale* L.

Inoculated but not infected: *Agropyron desertorum* Schult., *A. imbricatum* Roem. and Schult., *A. sibericum* Beauv., *Agrostis alba* L., *A. sto-*

lonifera Vasey, *Alopecurus geniculatus* L., *Anthoxanthum odoratum* L., *Beckmannia erucaeformis* (L.) Host., *Bromus erectus* Huds., *B. inermis* Leyss., *Calamagrostis canadensis* (Michx.) Beauv., *Cynodon dactylon* (L.) Pers., *Cynosurus cristatus* L., *Festuca ovina* L., *F. rubra* L., *Holcus lanatus* L., *Koeleria cristata* (L.) Pers., *Lolium italicum* R. Br., *L. perenne* L., *L. temulentum* L., *Poa nemoralis* L.

The results obtained by the writers in the main substantiate and extend those previously obtained by Carleton (6, 7) in this country, who says (7, p. 16)—

(1) that the forms of black stem rust on wheat, barley, *Hordeum jubatum*, *Agropyron tenerum*, *A. richardsoni*, *Elymus canadensis*, and *E. canadensis glaucifolius* are identical, with the probability that those on *Elymus virginicus*, *E. virginicus muticus*, and *Holcus lanatus* should be included; (2) that the black stem rust of *Agropyron occidentale* is physiologically distinct from any other.

The writers were unable to infect *Holcus lanatus*, although only a limited number of trials were made. *Agropyron smithii* (*A. occidentale*) is a very common host for both *P. graminis tritici* and *P. graminis secalis* in the upper Mississippi Valley. All the stemrust which the writers found was one of these two forms.

Eriksson (11, p. 601) gives *Triticum vulgare* as a host for wheat stemrust in Sweden, and states that barley, rye, and oats are sometimes weakly infected. The writers' results agree in general, except that barley is a very congenial host for the rust in this country, a fact previously noted by Carleton. Rye is weakly infected in a very characteristic manner. The production of uredinia in dead leaf areas (see pl. 53) is quite characteristic, although small uredinia may be produced without the killing of large areas. Rye is usually hypersensitive to the rust. Oats are infected rarely and with great difficulty.

Jaczewski (18, p. 353) gives *Triticum vulgare* as a host and says that *Hordeum vulgare*, *Triticum repens*, *T. caninum*, *Lolium perenne*, and *Festuca gigantea* can be infected, while *Secale cereale*, *Avena sativa*, *Dactylis glomerata*, *Bromus inermis*, and *B. secalinus* are immune. However, the writers have been able to infect both *Secale cereale* and *Avena sativa*.

In the spring-wheat-growing States some of the commonest grasses are very susceptible to wheat stemrust. The common species of Agropyron, except *A. repens*, are very congenial hosts. All of the species of Elymus and the closely related Hystrix which were tried are very susceptible, as well as the species of Hordeum. Of the cereals rye may rarely be affected with the rust in the field, and natural infection rarely, if ever, occurs on oats. Barley is very commonly affected, more often, probably, than with rye stemrust, to which it is also susceptible. *Bromus tectorum* is moderately susceptible, the uredinia usually remaining small and often round.

Only a few grasses besides the common hosts have been infected in the greenhouse. Oats and two of the grasses which are common hosts

for oat stemrust can be very rarely and weakly infected. On these hosts the uredinia were always very minute and often surrounded by an extremely small dead area.

There seem to be no marked differences in the rust on different hosts or in different parts of the upper Mississippi Valley and the northern Great Plains area. There appeared sometimes to be differences in virulence, but these were neither very constant nor very distinct. Rust on wheat kindly sent by Dr. F. Stoward from Leederville, West Australia, also behaved exactly like common *P. graminis tritici.* West of the Rocky Mountains, on the other hand, the rust on club wheat and grasses susceptible to *P. graminis tritici* is quite different, as previously noted.

TABLE XXIX.—*Results of inoculations with urediniospores of P. graminis tritici compacti*

Original host.	Immediate host.	Plant inoculated.	Trials.		Result.	Degree of infection.
			+	−		
Triticum compactum	*Triticum compactum*	*Agropyron cristatum*	1	0	14/24	Moderate.
Do	do	*Agropyron desertorum*	1	0	2/20	Weak.
Do	do	*Agropyron elongatum*	1	0	10/22	
Do	do	*Agropyron imbricatum*	0	1	0/30	Do.
Do	do	*Agropyron intermedium*	1	0	3/12	Do.
Do	*Hordeum vulgare*	*Agropyron repens*	1	0	2/22	Do.
Do	do	*Agropyron tenerum*	1	0	7/9	Moderate.
Do	*Triticum compactum*	do	1	0	10/20	Do.
Elymus glaucus	*Hordeum vulgare*	*Agrostis alba*	0	1	0/70	
Do	do	*Agropyron stolonifera*	0	1	0/35	
Triticum compactum	*Triticum compactum*	do	0	1	0/60	
Do	do	*Alopecurus geniculatus*	0	1	0/50	
Elymus glaucus	*Hordeum vulgare*	*Alopecurus pratensis*	0	1	0/38	
Triticum compactum	*Triticum compactum*	do	0	1	0/60	
Do	do	*Anthoxanthum odoratum*	0	1	0/70	
Elymus glaucus	*Hordeum vulgare*	do	0	1	0/75	
Do	do	*Avena sativa*	0	1	0/37	
Triticum compactum	*Triticum compactum*	do	0	2	0/75	
Elymus glaucus	*Hordeum vulgare*	do	0	2	0/38	
Triticum compactum	do	*Bromus tectorum*	1	0	40/40	Weak.

TABLE XXIX.—*Results of inoculations with urediniospores of P. graminis tritici compacti*—Continued

Original host.	Immediate host.	Plant inoculated.	Trials. +	Trials. −	Result.	Degree of infection.
Triticum compactum	*Triticum compactum*	*Elymus canadensis*	1	0	20/20	Heavy.
Do	do	*Holcus lanatus*	0	1	0/50	
Do	do	*Hordeum jubatum*	1	0	30/30	Do.
Triticum compactum, *Elymus glaucus*	Various	*Hordeum vulgare*	12	0	305/336	Do.
Triticum compactum	*Triticum compactum*	*Koeleria cristata*	0	1	0/25	
Do	do	*Phleum pratense*	0	1	0/20	
Do	do	*Poa compressa*	0	1	0/15	
Elymus glaucus	*Secale cereale*	*Secale cereale*	0	1	0/14; 8	
Triticum compactum	*Triticum compactum*	do	2	0	3/29; 10	Weak.
Elymus glaucus	*Hordeum vulgare*	do	2	0	4/18; 3	Do.
Triticum compactum	*Triticum compactum*	*Triticum compactum*	7	0	238/242	Very heavy.
Do	*Hordeum vulgare*	do	1	0	34/34	Do.
Do	*Triticum vulgare*	do	1	0	10/12	Do.
Elymus glaucus	*Hordeum vulgare*	do	4	0	33/38	Do.
Elymus candensatus	*Triticum vulgare*	do	2	0	43/51	Do.
Do	*Triticum compactum*	do	2	0	106/109	Do.
Do	do	*Triticum dicoccum* [a]	2	0	38/43	Variable, mostly weak.
Elymus glaucus	*Hordeum vulgare*	do	3	0	24/36	Weak.
Triticum compactum	*Triticum compactum*	do	2	0	21/26	Do.
Elymus condensatus	do	*Triticum durum*	6	0	104/122	Weak to moderate.
Elymus glaucus	*Hordeum vulgare*	do	3	0	49/50	Moderate.
Do	do	*Triticum monococcum*	1	0	15/15	Heavy.
Elymus condensatus	*Triticum compactum*	do	2	0	24/39	Moderate to heavy.
Do	do	*Triticum vulgare*	6	0	128/136	Variable; mostly weak.
Triticum compactum	do	do	7	0	69/81	Do.
Do	*Hordeum vulgare*	do	2	0	54/69	Weak.
Do	*Triticum vulgare*	do	2	0	18/31	Do.
Elymus glaucus	*Hordeum vulgare*	do	11	0	161/177	Do.

[a] A number of different varieties of *Triticum dicoccum*, *T. durum*, *T. monococcum*, and *T. vulgare* were tried. There was sometimes a varietal difference in susceptibility.

The results of inoculations with *P. graminis tritici compacti* can be summarized as follows:

Hosts on which the rust has been found in nature: *Agropyron smithii* Rydb., *Elymus canadensis* L., *E. condensatus* Presl., *E. glaucus* Buckley, *E. macounii* Vasey, *Hordeum jubatum* L., *Triticum compactum* Host.

Hosts easily infected by artificial inoculation: *Agropyron cristatum* J. Gaert., *A. elongatum* Host., *A. tenerum* Vasey, *Bromus tectorum* L., *Hordeum vulgare* L., *Triticum durum* Desf. (some varieties), *Triticum monococcum* L., *T. vulgare* Vill. (a few varieties).

Weakly infected by artificial inoculation: *Agropyron desertorum* Schult., *A. intermedium* Beauv., *A. repens* (L.) Beauv., *Secale cereale* L., *Triticum dicoccum* Schr., *T. durum* Desf. (some varieties), *T. vulgare* Vill. (most varieties tried).

Artificially inoculated but not infected: *Agrostis alba* L., *A. stolonifera* Vasey, *Alopecurus geniculatus* L., *A. pratensis* L., *Anthoxanthum odoratum* L., *Avena sativa* L., *Holcus lanatus* L., *Koeleria cristata* (L.) Pers., *Phleum pratense* L., *Poa compressa* L.

It is quite evident that this rust is very similar in many respects to *P. graminis tritici*. However, its behavior on most varieties of *Triticum vulgare* so far inoculated is so very different from that of *P. graminis tritici* that it can scarcely be included in the latter form. All of the hard spring wheats, including Minnesota 169, Minnesota 163, Marquis, and Preston, are very resistant to *P. graminis tritici compacti*, showing a high degree of hypersensitiveness, while they are very susceptible to *P. graminis tritici*. (See Pl. 53–56.) The same is true of the hard winter wheats which have been inoculated. The soft wheats are, however, more susceptible. It is on account of its very distinctive action on the hard wheats of the *vulgare* group that it seems desirable to apply a distinct name in order to avoid confusion. The morphology of the uredíniospores is also somewhat different from that of any of the other forms.

P. tritici compacti has been found only in the Palouse country, where it seems to be very common on wild grasses and on club wheats. Whether ordinary *P. graminis tritici* also occurs in that region, the writers have not yet been able to determine. All the rust collected on wild grasses and cereals was the *tritici compacti* form.

The degree of stability or fixity of the rust should be thoroughly investigated. It is possible that it is an easily changed variant strain of ordinary *P. graminis tritici*, although all attempts made by the writers to change its parasitic tendencies by confining it for a number of successive generations to an uncongenial host or by the use of possible bridging hosts have been unsuccessful.

TABLE XXX.—*Results of inoculations with urediniospores of Puccinia graminis secalis*

Original host.	Immediate host.	Plant inoculated.	Trials. +	Trials. −	Result.	Degree of infection.
Agropyron repens	*Hordeum vulgare*	*Agropyron caninum*	2	0	14/68	Moderate.
Hystrix patula	*Secale cereale*	do	1	0	1/3	Do.
Agropyron repens	*Hordeum vulgare*	*Agropyron cristatum*	1	0	26/28	Heavy.
Agropyron cristatum	do	do	1	0	3/15	Moderate.
Hordeum jubatum	do	do	2	0	29/42	Moderate to heavy.
Agropyron repens	do	*Agropyron desertorum*	0	2	0/22	
Secale cereale	*Secale cereale*	do	1	0	1/25	Weak.
Agropyron repens	*Hordeum vulgare*	*Agropyron imbricatum*	1	2	1/50	Do.
Secale cereale	*Secale cereale*	do	0	1	0/20	
Agropyron repens	*Hordeum vulgare*	*Agropyron intermedium*	0	1	0/6	
Secale cereale	*Secale cereale*	do	1	0	5/13	Do.
Agropyron smithii	do	*Agropyron repens*	1	0	34/34	Heavy.
Agropyron repens	do	do	1	0	13/32	Do.
Do	*Hordeum vulgare*	do	2	0	51/57	Do.
Do	*Agropyron repens*	do	1	0	10/12	Do.
Do	*Elymus canadensis*	do	1	0	23/23	Do.
Do	*Elymus robustus*	do	1	0	21/21	Do.
Secale cereale	*Secale cereale*	do	3	0	129/130	Do.
Hystrix patula	*Hordeum vulgare*	do	1	0	15/15	Do.
Agropyron repens	do	*Agropyron sibericum*	0	2	0/48	
Agropyron smithii	do	*Agropyron smithii*	2	0	10/12	Do.
Agropyron repens	do	do	2	0	17/61	Moderate.
Hordeum jubatum	do	do	1	0	6/6	Heavy.
Agropyron cristatum	*Secale cereale*	*Agropyron tenerum*	1	0	72/72	Do.
Do	*Hordeum vulgare*	do	1	0	16/16	Do.
Agropyron repens	do	do	2	0	12/63	Moderate.
Do	*Elymus virginicus*	do	1	0	62/78	Heavy.
Do	*Hordeum jubatum*	do	1	0	4/18	Light.

TABLE XXX.—*Results of inoculations with urediniospores of Puccinia graminis secalis*—Continued

Original host.	Immediate host.	Plant inoculated.	Trials. +	Trials. −	Result.	Degree of infection.
Agropyron repens	*Agropyron tenerum*	*Agropyron tenerum*	8	0	286/340	Moderate to heavy.
Hordeum jubatum	*Hordeum vulgare*	do	6	0	60/60	Heavy.
Hystrix patula	*Elymus virginicus*	do	1	0	52/60	Do.
Do	*Agropyron tenerum*	do	8	0	305/338	Moderate to heavy.
Agropyron repens	*Elymus virginicus*	*Agrostis alba*	0	1	0/50	
Secale cereale	*Secale cereale*	do	0	2	0/110	
Do	do	*Agrostis stolonifera*	0	1	0/65	
Hordeum jubatum	*Hordeum vulgare*	*Alopecurus geniculatus*	0	1	0/24	
Do	do	*Alopecurus pratensis*	0	1	0/70	
Secale cereale	*Secale cereale*	do	0	1	0/40	
Do	do	*Anthoxanthum odoratum*	0	1	0/45	
Agropyron repens	*Hordeum vulgare*	*Arrhenatherum elatius*	0	1	0/10	
Do	do	*Avena fatua*	0	1	0/10	
Do	do	*Avena sativa*	0	1	0/19	
Do	*Agropyron repens*	do	0	1	0/19	
Do	*Secale cereale*	do	0	1	0/14	
Secale cereale	*Hordeum vulgare*	do	1	2	3/101	
Do	*Secale cereale*	do	3	1	8/167	Weak.
Agropyron repens	*Elymus virginicus*	*Bromus purgans*	1	0	2/16	Do.
Do	*Hordeum vulgare*	*Bromus tectorum*	2	0	53/70	Light.
Secale cereale	*Secale cereale*	*Dactylis glomerata*	0	1	0/24	
Agropyron repens	*Hordeum jubatum*	do	0	1	0/12	
Do	*Secale cereale*	*Elymus canadensis*	1	0	26/27	Heavy.
Do	*Agropyron repens*	do	1	0	11/11	Do.
Do	*Hordeum vulgare*	do	1	0	17/17	Do.
Do	*Elymus canadensis*	do	11	0	328/371	
Do	*Hordeum vulgare*	do	1	0	7/12	Do.
Do	*Elymus robustus*	do	1	0	23/23	Do.

TABLE XXX.—*Results of inoculations with urediniospores of Puccinia graminis secalis*—Continued

Original host.	Immediate host.	Plant inoculated.	Trials.		Result.	Degree of infection.
			+	−		
Elymus canadensis	*Secale cereale*	*Elymus canadensis*	1	0	12/12	Heavy.
Agropyron repens	do	*Elymus robustus*	1	0	28/30	Do.
Do	*Hordeum vulgare*	do	2	0	35/35	Do.
Do	*Elymus robustus*	do	12	0	233/264	Do.
Do	*Secale cereale*	*Elymus virginicus*	1	0	23/29	Do.
Do	*Agropyron repens*	do	1	0	6/7	Do.
Do	*Elymus virginicus*	do	11	0	414/436	Moderate to heavy.
Do	*Hordeum vulgare*	do	2	0	30/35	Heavy.
Do	*Elymus canadensis*	do	1	0	7/7	Do.
Do	*Hordeum jubatum*	do	1	0	7/15	Moderate.
Do	*Hordeum vulgare*	do	2	0	56/60	Heavy.
Hystrix patula	do	do	1	0	26/26	Do.
Do	*Elymus virginicus*	do	2	0	52/54	Do.
Secale cereale	*Secale cereale*	*Holcus lanatus*	0	1	0/26	
Agropyron repens	*Agropyron repens*	*Hordeum jubatum*	1	0	14/28	Do.
Do	*Elymus robustus*	do	2	0	13/34	Moderate.
Do	*Hordeum jubatum*	do	6	0	228/263	Heavy.
Do	*Elymus virginicus*	do	2	0	23/47	Light.
Hystrix patula	*Agropyron tenerum*	do	1	0	33/40	Heavy.
Do	*Hordeum jubatum*	do	5	0	142/184	Moderate to heavy.
Agropyron repens	*Elymus virginicus*	*Hordeum pusillum*	1	0	70/70	Moderate.
Do	*Hordeum vulgare*	*Hordeum vulgare* (Abyssinian).	3	0	49/57	Do.
Do	do	*Hordeum vulgare pallidum*, subvar. *pyramidatum*.	1	0	6/12	Do.
Do	do	*Hordeum spontaneum*	1	0	7/7	Do.
Do	do	*Hordeum vulgare pallidum*.	1	0	28/28	Do.
Do	*Elymus virginicus*	*Hystrix patula*	1	0	18/18	Do.
Hystrix patula	do	do	1	1	22/40	Heavy.
Agropyron repens	*Hordeum vulgare*	*Koeleria cristata*	0	1	0/30	

TABLE XXX.—*Results of inoculations with urediniospores of Puccinia graminis secalis*—Continued

Original host.	Immediate host.	Plant inoculated.	Trials.		Result.	Degree of infection.
			+	−		
Agropyron repens	*Agropyron repens*	*Lolium perenne*	0	1	0/17	
Do	*Elymus virginicus*	do	0	1	0/19	
Do	*Hordeum vulgare*	*Phalaris canariensis*	0	1	0/19	
Do	do	*Triticum compactum*	0	1	0/24	
Do	do	*Triticum vulgare* [a]	3	12	3/454	
Do	*Elymus robustus*	do	0	5	0/147	
Do	*Elymus canadensis*	do	1	10	1/394	

[a] Only a few of the results with wheat are recorded here; they will appear later.

The results of the survey work and of the inoculations with known strains of *P. graminis secalis* can be summarized as follows: *P. graminis secalis* has been found on the following hosts in the field: *Agropyron caninum* (L.) Beauv., *A. cristatum* J. Gaert., *A. smithii* Rydb., *A. repens* (L.) Beauv., *A. tenerum* Vasey, *Elymus canadensis* L., *E. robustus* Scribn. and J. G. Sm., *Hordeum jubatum* L., *H. pusillum* Nutt., *H. vulgare* L., *Hystrix patula* Moench., *Secale cereale* L., *Sporobolus cryptandrus* (Torr.) Gray.

In addition to the above, the following have been easily infected by artificial inoculation: *Agropyron elongatum* Host., *Bromus tectorum* L., *Elymus virginicus* L., *Hordeum spontaneum* K. Koch, *H. vulgare pallidum* Ser., *H. vulgare pallidum* subvar. *pyramidatum*.

The following have been weakly infected artificially: *Agropyron imbricatum* Roem., and Schult., *A. intermedium* Beauv., *A. sibericum* Beauv., *Avena sativa* L., *Bromus purgans* L., *Triticum vulgare* Vill.

Inoculated but not infected: *Agropyron desertorum* Schult., *Agrostis alba* L., *A. stolonifera* Vasey, *Alopecurus geniculatus* L., *A. pratensis* L., *Anthoxanthum odoratum* L., *Arrhenatherum elatius* (L.) Beauv., *Avena fatua* L., *Dactylis glomerata* L., *Holcus lanatus* L., *Koeleria cristata* (L.) Pers., *Lolium perenne* L., *Phalaris canariensis* L., *Triticum compactum* Host.

Little work has been done on the wild hosts for *P. graminis secalis* in this country. Carleton (6. p. 60) reports successful infection of rye and barley, but not of wheat, with—

> what seemed to be uredospores of *P. graminis* from *Hordeum jubatum*

and concludes in a preliminary way that *Hordeum jubatum* supports two distinct forms of *P. graminis*. These two forms, in the light of the writers'

experiments, are *P. graminis tritici* and *P. graminis secalis*, both of which infect *H. jubatum* easily and both of which are commonly found on the grass in the field. Freeman and Johnson (14, p. 21, 28) showed that stemrust of rye infects both rye and barley, but did not work with the grass hosts. Pritchard (22, p. 181), as a result of work done in North Dakota, concludes—

> that one form of *P. graminis* is common to *Hordeum jubatum, Agropyron tenerum, A. repens, Avena fatua*, oats, and rye, but is incapable of infecting either barley or wheat.

Pritchard very probably worked with two forms—viz, (1) *P. graminis secalis*, which probably caused the infection of *Hordeum jubatum, Agropyron tenerum, A. repens*, and rye; and (2) *P. graminis avenae*, which infected the oats, and *A. fatua*.

In Sweden Eriksson (11, p. 601) did considerable work on the grass hosts of rye stemrust, and gives the following as hosts:

> *Secale cereale, Hordeum vulgare, H. jubatum, H. murinum, H. comosum, Triticum repens, T. caninum, T. desertorum, Elymus arenarius, E. sibericus*, and *Bromus secalinus*.

It is quite apparent that this rust in Sweden is very similar, if not identical, with that in this country. Eriksson mentions *Triticum* (*Agropyron*) *desertorum* as a host; the writers were not able to infect this host in the greenhouse, but the number of trials was too small to justify definite conclusions. While the species of grasses with which Eriksson and the writers worked are not all the same, the same genera were investigated, and some species of these genera were found as hosts for the rusts in both countries. It is very probable, although by no means certain, that most of the species of Agropyron, Hordeum, Elymus, and Hystrix are susceptible to rye stemrust.

Jaczewski's results in Russia do not agree closely with those of Eriksson nor those recorded in this paper. He mentions *Secale cereale* (18, p. 353) as the host, and states that the rust is capable of infecting *Triticum repens, T. caninum*, and *Dactylis glomerata*. The writers were unable to infect *D. glomerata* with stemrust of rye, although only 46 leaves were inoculated. It is entirely possible that the rust can infect *D. glomerata* weakly, but it is improbable that it does so commonly enough to be of practical significance. Jaczewski states that *Hordeum vulgare* is immune to the rust. In this country it is very susceptible.

The stemrust of rye in this country easily infects rye and barley, but very rarely, or scarcely at all, wheat and oats. Of the wild grass hosts *Agropyron repens* is by far the most common. It is nearly always severely affected. Although *A. repens* can be infected weakly by *P. graminis tritici* also, it is doubtful if the wheat stemrust occurs on it, unless quite exceptionally, in the field. In general the various species of Agropyron, Elymus, Hordeum, and Hystrix are hosts for the rust. It is found commonly on at least some species of all these genera in the field.

It is noteworthy that the stemrust of rye and the stemrust of wheat have so many hosts in common, especially since wheat is practically immune to *P. graminis secalis* and rye is very highly resistant to *P. graminis tritici*.

TABLE XXXI.—*Results of inoculations with urediniospores of P. graminis avenae*

Original host.	Immediate host.	Plant inoculated.	Trials.		Result.	Degree of infection.
			+	−		
Dactylis glomerata	*Avena sativa*	*Agropyron caninum*	0	3	0/61	
Do	do	*Agropyron cristatum*	1	0	3/25	
Do	do	*Agropyron desertorum*	0	1	0/30	
Do	do	*Agropyron elongatum*	0	1	0/25	
Do	do	*Agropyron imbricatum*	0	1	0/20	
Do	do	*Agropyron intermedium*	0	1	0/25	
Do	do	*Agropyron repens*	0	3	0/98	
Do	do	*Agropyron smithii*	0	4	0/54	
Do	do	*Agropyron tenerum*	0	2	0/35	
Do	do	*Agrostis alba*	1	1	30/480	Moderate.
Agrostis exarata	do	do	1	0	7/30	Light.
Dactylis glomerata	do	*Agrostis stolonifera*	0	3	0/123	Strong flecks
Avena sativa	do	do	0	1	0/40	
Agrostis exarata	do	do	3	0	21/100	Light to moderate.
Panicularia pauciflora	do	do	1	0	5/10	Moderate.
Dactylis glomerata	do	*Alopecurus geniculatus*	1	0	27/35	Do.
Agrostis exarata	do	do	1	0	30/42	Do.
Dactylis glomerata	do	*Alopecurus pratensis*	2	1	119/165	Heavy.
Agrostis exarata	do	do	1	0	35/35	Moderate.
Dactylis glomerata	do	*Anthoxanthum odoratum*	2	2	76/183	Do.
Do	do	*Arrhenatherum elatius*	4	2	17/200	Light to moderate.
Do	*Avena fatua*	do	1	0	2/11	Light.
Do	*Avena sativa*	*Avena fatua*	1	0	43/44	Heavy.
Do	*Avena fatua*	do	1	0	40/40	Do.
Do	*Avena sativa*	*Beckmannia erucaeformis*	1	0	1/17	Small uredinium.
Avena sativa	do	do	0	1	0/9	

TABLE XXXI.—*Results of inoculations with urediniospores of P. graminis avenae*—Continued

Original host.	Immediate host.	Plant inoculated.	Trials.		Result.	Degree of infection.
			+	−		
Dactylis glomerata	*Avena sativa*	*Bromus erectus*	1	1	1/17	Light.
Do	*Bromus tectorum*	do	1	0	2/18	Do.
Do	*Avena sativa*	*Bromus hordeaceus*	0	1	0/8	
Do	*Bromus tectorum*	do	0	1	0/34	
Do	*Avena sativa*	*Bromus inermis*	0	1	0/40	
Avena sativa	do	*Bromus pumila*	0	1	0/10	
Dactylis glomerata	do	*Bromus purgans*	1	0	1/23	Do.
Do	do	*Bromus tectorum*	5	0	194/194	Light to moderate.
Do	do	*Calamagrostis canadensis.*	1	0	2/13	Moderate.
Avena sativa	do	do	0	1	0/12	
Panicularia pauciflora	do	do	1	0	12/15	Do.
Agrostis exarata	do	do	1	0	20/25	
Dactylis glomerata	do	*Cynodon dactylon*	0	1	0/14	
Do	do	*Cynosurus cristatus*	0	2	0/60	
Avena sativa	do	do	0	1	0/30	
Dactylis glomerata	do	*Dactylis glomerata*	3	0	51/79	Heavy.
Panicularia pauciflora	do	do	1	0	7/7	Do.
Agrostis exarata	do	do	1	0	12/12	Do.
Avena sativa	do	*Danthonia spicata*	0	1	0/36	
Do	do	*Deschampsia flexuosa*	0	1	0/3	
Dactylis glomerata	*Avena fatua*	*Elymus canadensis*	1	0	2/20	Small uredinia.
Do	*Avena sativa*	do	3	3	14/265	Weak.
Do	*Avena fatua*	*Elymus robustus*	1	0	1/20	Small uredinium.
Do	*Avena sativa*	do	3	2	3/138	Do.
Do	*Avena fatua*	*Elymus virginicus*	0	1	0/20	
Do	*Avena sativa*	do	0	4	0/140	
Do	do	*Festuca elatior*	3	0	11/163	Weak.
Avena sativa	do	do	1	0	1/21	Do.
Dactylis glomerata	do	*Festuca ovina*	1	1	4/37	Moderate.

TABLE XXXI.—*Results of inoculations with urediniospores of P. graminis avenae*—Continued

Original host.	Immediate host.	Plant inoculated.	Trials.		Result.	Degree of infection.
			+	−		
Avena sativa	*Avena sativa*	*Festuca ovina*	0	1	0/17	
Dactylis glomerata	do	*Festuca rubra*	0	1	0/17	
Avena sativa	do	do	0	1	0/28	
Dactylis glomerata	do	do	0	2	0/30	
Do	do	*Holcus lanatus*	2	1	55/190	Moderate.
Avena sativa	do	do	1	0	1/13	Small uredinium.
Agrostis exarata	do	do	1	0	25/30	Moderate.
Dactylis glomerata	do	*Hordeum jubatum*	0	2	0/55	
Do	do	*Hordeum pusillum*	1	0	4/28	Small uredinia.
Do	do	*Hordeum spontaneum*	1	0	3/6	Minute uredinia.
Do	do	*Hordeum vulgare*	14	2	27/471	Do.
Do	*Avena fatua*	do	1	0	1/36	Do.
Do	*Koeleria cristata*	do	0	1	0/13	
Do	*Bromus tectorum*	do	1	0	3/36	Do.
Avena sativa	do	do	1	0	3/26	Small uredinia.
Panicularia pauciflora	*Avena sativa*	do	1	0	12/14	Heavy.
Agrostis exarata	do	do	1	0	11/16	Moderate.
Anthoxanthum puelii	do	do	1	0	9/13	Minute uredinia.
Panicularia pauciflora	*Hordeum vulgare*	do	1	1	3/53	
Dactylis glomerata	*Avena sativa*	*Hordeum vulgare* (Abyssinian).	1	2	1/42	Do.
Do	do	*Hordeum vulgare pallidum.*	0	1	0/11	
Do	do	*Hordeum vulgare Pallidum* subvar. *pyramidatum.*	0	1	0/19	
Do	do	*Hystrix patula*	1	0	1/19	Small uredinia.
Do	do	*Koeleria cristata*	1	0	15/20	Heavy.
Do	*Avena fatua*	*Lolium italicum*	0	1	0/22	
Do	*Avena sativa*	do	1	2	2/151	Weak.
Do	do	*Lolium perenne*	2	2	5/191	Do.
Do	do	*Lolium temulentum*	2	0	16/55	Moderate.

TABLE XXXI.—*Results of inoculations with urediniospores of P. graminis avenae*—Continued

Original host.	Immediate host.	Plant inoculated.	Trials. +	Trials. −	Result.	Degree of infection.
Dactylis glomerata	*Avena sativa*	*Phalaris canariensis*	1	0	17/19	Moderate.
Agrostis exarata	*Dactylis glomerata*	*Phleum pratense*	1	0	1/15	Weak.
Anthoxanthum puelii	*Avena sativa*	do	1	0	3/79	Do.
Dactylis glomerata	do	do	1	0	5/50	Do.
Panicularia pauciflora	*Dactylis glomerata*	do	1	0	7/35	Do.
Do	*Phleum pratense*	do	0	1	0/7	
Dactylis glomerata	*Avena sativa*	*Poa nemoralis*	0	1	0/10	
Do	do	*Poa compressa*	0	2	0/44	
Do	do	*Savastana odorata*	0	1	0/6	
Avena sativa	do	do	0	1	0/15	
Dactylis glomerata	do	*Secale cereale*	3	4	9/301	Minute uredinia.
Do	*Avena fatua*	do	1	0	4/34	Do.
Do	*Bromus tectorum*	do	0	1	0/17	
Agrostis exarata	*Avena sativa*	do	0	1	0/11;3	
Panicularia pauciflora	do	do	3	0	8/50	Do.
Dactylis glomerata	do	*Triticum vulgare*	0	9	0/431	
Panicularia pauciflora	do	do	0	2	0/26	

The results of the field-survey work and inoculations in the greenhouse with *P. graminis avenae* are given in the following summary:

Hosts found naturally infected: *Avena sativa* L., *A. fatua* L., *Agrostis exarata* Trin., *Anthoxanthum puelli* Lecoq. and Lamotte, *Dactylis glomerata* L., *Koeleria cristata* (L.) Pers., *Panicularia pauciflora* (Presl.) Kuntze.

Easily infected by artificial inoculation: *Arrhenatherum elatius* (L.) Beauv., *Alopecurus geniculatus* L., *A. pratensis* L., *Bromus tectorum* L., *Calamagrostis canadensis* (Michx.) Beauv., *Holcus lanatus* L., *Phalaris canariensis* L.

Weakly infected by artificial inoculation: *Agropyron cristatum* J. Gaert., *Agrostis alba* L., *A. stolonifera* Vasey, *Beckmannia erucaeformis* (L.) Host., *Bromus erectus* Huds., *B. purgans* L., *Elymus canadensis* L., *E. robustus* Scribn. and J. G. Sm., *Festuca elatior* L., *F. ovina* L., *Hordeum pusillum* Nutt., *H. vulgare* L., *H. vulgare pallidum* Ser., *H. vulgare*

pallidum subvar. *pyramidatum*, *H. spontaneum* K. Koch, *Hystrix patula* Moench., *Lolium italicum* R. Br., *L. perenne* L., *L. temulentum* L., *Phleum pratense* L., *Secale cereale* L.

Inoculated but not infected: *Agropyron caninum* (L.) Beauv., *A. desertorum* Schult., *A. elongatum* Host., *A. imbricatum* Roem. and Schult., *A. intermedium* Beauv., *A. repens* (L.) Beauv., *A. smithii* Rydb., *A. tenerum* Vasey, *Bromus inermis* Leyss., *B. pumila*, *Cynodon dactylon* (L.) Pers., *Cynosurus cristatus* L., *Danthonia spicata* (L.) Beauv., *Deschampsia flexuosa* (L.) Trin., *Elymus virginicus* L., *Festuca rubra* L., *Hordeum jubatum* L., *H. spontaneum* K. Koch, *H. vulgare pallidum* Ser. *H. vulgare pallidum* subvar. *pyramidatum*, *Poa compressa* L., *Savastana odorata* (L.) Scribn., *Triticum vulgare* Vill.

Carleton (6, p. 63–64) gives the following as hosts for stemrust of oats: *Avena sativa patula*, *A. sativa orientalis*, and *A. sativa nuda* (cultivated varieties and *Dactylis glomerata* and *Arrhenatherum elatius*. The following he considers as probable hosts: *Avena fatua*, *A. hookeri*, *A. pratensis*, *A. sterilis*, *Koeleria cristata* and *Lolium perenne*. The writers have shown that *A. fatua*, and *Koeleria cristata* are undoubtedly hosts and that *Lolium perenne* can be infected, although whether or not it is commonly a host has not been determined. Carleton's results and those of the writers are in general agreement with those of Eriksson (11, p. 601) in Sweden, although the same species were not used in inoculation experiments in all cases. Jaczewski (18, p. 353), on the other hand, arrived at different conclusions as a result of his work in Russia. The most striking difference is that he gives *Dactylis glomerata* as immune, whereas in this country it is one of the very common hosts. Eriksson and Henning also give it as one of the hosts in Sweden. It would be interesting to know whether the rust is really different in Russia or whether for some reason *D. glomerata* did not become infected in the limited number of trials which Jaczewski made.

A number of investigators have called attention to the versatility of the oat stemrust. There is no doubt that it can infect many different grasses.

It is interesting to notice the varying degrees of virulence of the rust on different hosts. It is extremely virulent on such hosts as *Avena sativa*, *A. fatua*, and *Dactylis glomerata*, while on *Alopecurus pratensis* it is moderately virulent, on *Holcus lanatus* a little less virulent, on *Agrostis alba* still less virulent, on *Hordeum vulgare* and *Secale cereole* it develops very imperfectly, and on *Triticum vulgare* it scarcely ever even produces flecks.

The stemrust of oats is similar to *P. phleipratensis* and *P. graminis agrostis* in its ability to infect plants in such varying degrees. (See Pl. 57–59.) The other biologic forms do not seem to behave in this way. The wheat stemrust and the rye stemrust sometimes infect plants weakly, but, as a rule, they either cause heavy infection or none at all.

The facts cited above raise an interesting question which the writers have not yet been able to answer—namely, Is *P. graminis avenae* a plastic form or is it a composite form from which the component forms can be isolated by culture on various hosts? Morphological studies of the stemrust of oats made by Mr. M. N. Levine, of this Station, not yet published, show that *P. graminis avenae* is very variable morphologically, more variable than any of the other biologic forms. Spores practically indistinguishable from those of *P. phleipratensis*, and others very similar to those of *P. graminis agrostis*, are commonly produced by *P. graminis avenae*. The infection capabilities of the three rusts are similar. These facts may be of some significance, but, at present, speculation only is possible.

Stemrust of oats was found very commonly in the region covered by the survey. It was very prevalent on grasses in the western mountain valleys, and, on account of the large number of possible hosts, it is quite probable that grasses are quite important in its spread and possibly as a means of its overwintering. Unfortunately no studies on this phase of the problem have yet been made. They are highly important and will be made as soon as possible.

TABLE XXXII.—*Results of inoculations with urediniospores of P. graminis phleipratensis*

Original host.	Immediate host.	Plant inoculated.	Trials.		Result.	Degree of infection.
			+	−		
Phleum pratense	*Phleum pratense*	*Agrostis alba*	0	2	0/165	
Festuca elatior	do	*Alopecurus geniculatus*	1	0	65/70	Moderate.
Do	do	*Alopecurus pratensis*	2	0	37/60	Moderate to heavy.
Do	do	*Avena sativa*	1	0	1/28	
Do	*Avena sativa*	do	5	2	22/96	Weak.
Phleum pratense	*Phleum pratense*	*Festuca elatior*	1	0	36/36	Heavy.
Do	do	*Festuca ovina*	0	1	0/17	
Do	do	*Festuca rubra*	0	1	0/11	
Festuca elatior	do	*Holcus lanatus*	1	0	25/30	Moderate.
Do	do	*Hordeum vulgare*	1	0	7/29	
Festuca pratensis	*Hordeum vulgare*	do	2	3	14/50	Weak.
Festuca elatior	*Phleum pratense*	*Koeleria cristata*	1	0	35/40	Heavy.
Do	do	*Poa compressa*	0	1	0/15	
Do	do	*Secale cereale*	1	0	1/30	
Do	do	*Triticum vulgare*	0	1	0/22	

Hosts on which *P. graminis phleipratensis* was found in nature: *Dactylis glomerata* L., *Festuca elatior* L., *F. pratensis* Huds., *Koeleria cristata* (L.) Pers., *Phleum pratense* L.

Hosts heavily infected by artificial inoculation: *Alopecurus geniculatus* L., *A. pratensis* L., *Holcus lanatus* L.

Weakly infected by artificial inoculation: *Avena sativa* L., *A. fatua* L., *Arrhenatherum elatius* (L.) Beauv., *Bromus tectorum* L., *Elymus virginicus* L., *Hordeum jubatum* L., *H. vulgare* L., *Lolium italicum* R. Br., *L. perenne* L., *Secale cereale* L.

Inoculated but not infected: *Agropyron repens* (L.) Beauv., *Agrostis alba* L., *Festuca ovina* L., F. *rubra* L., *Poa compressa* L., *Triticum vulgare* Vill.

It will be observed that the timothy rust occurs in the field on *Dactylis glomerata*, *Festuca elatior*, and *F. pratensis* and probably *Koeleria cristata*, in addition to *Phleum pratense*. Eriksson and Henning (13, p. 130) give only *Phleum pratense* as a host plant, as does Johnson (19), although he succeeded in infecting *D. glomerata* and *F. elatior* by means of artificial inoculations. How commonly this rust occurs on *D. glomerata* the writers do not know; however, it does occur commonly on both species of Festuca mentioned.

The character of infection on the plants mentioned as weakly infected in the greenhouse has been previously discussed (26) and need not be repeated here.

The relation of the rust to *P. graminis* is still probably debatable. The problem has been summarized by Stakman and Jensen (26, p. 211). So far as the writers have been able to determine, no one has yet been able to infect barberry consistently with the teliospores. The writers made numerous inoculations in the spring and early summer of 1916 at a time when teliospores of the common biologic forms readily infected barberries, but no æcia developed as a result of the inoculations made with timothy-rust teliospores. Flecks were commonly developed, and, although histological examination was not made, it is quite probable that infection occurred, but the rust was unable to develop æcia. On morphological grounds there seems to be no justification for regarding timothy rust as a distinct species; it does not differ more from ordinary biologic forms of *P. graminis* than does *P. graminis agrostis*. The same is true of its infection capabilities. The writers favor including it as a biologic form of *P. graminis*.

The distribution of the rust is interesting. In 1911 Johnson (19, p. 7) stated that it was common at least as far west as Minnesota and in 1914 Mercer (21, p. 20–22) recorded it as being common in North Dakota. In 1916 the writers found it very commonly in serious abundance in Minnesota, North Dakota, Montana, Idaho, Washington, Wyoming, Nebraska, Iowa, and Manitoba, Canada.

TABLE XXXIII.—*Results of inoculations with urediniospores of P. graminis agrostis*

Original host.	Immediate host.	Plant inoculated.	Trials. +	Trials. −	Result.	Degree of infection.
Agrostis alba	*Agrostis alba*	*Alopecurus geniculatus*	1	0	70/85	Heavy.
Do	do	*Alopecurus pratensis*	1	0	20/30	Moderate to heavy.
Do	do	*Anthoxanthum odoratum.*	0	1	0/35	
Do	do	*Avena sativa*	2	0	4/36	Weak.
Do	*Avena sativa*	do	0	1	0/11	
Agrostis stolonifera	do	do	1	1	2/22	Do.
Do	do	*Bromus inermis*	0	1	0/7	
Do	do	*Bromus tectorum*	1	0	24/24	Moderate.
Do	*Agrostis alba*	*Calamagrostis canadensis.*	1	0	3/45	Do.
Agrostis alba	do	*Dactylis glomerata*	1	0	16/16	Heavy.
Do	do	*Holcus lanatus*	1	0	35/45	Moderate.
Do	do	*Hordeum jubatum*	0	1	0/24	
Do	do	*Hordeum vulgare*	1	0	7/26	Weak.
Do	*Hordeum vulgare*	do	3	1	13/35	Do.
Do	*Agrostis alba*	*Koeleria cristata*	1	0	12/18	Moderate.
Do	do	*Phalaris canariensis*	0	2	0/17	
Do	*Avena sativa*	*Phleum pratense*	0	1	0/4	
Do	*Agrostis alba*	*Poa compressa*	0	1	0/18	
Do	do	*Secale cereale*	1	0	2/17	Weak.
Agrostis stolonifera	*Secale cereale*	do	0	1	0/4	
Do	*Agrostis stolonifera*	*Triticum vulgare*	0	1	0/34	
Do	*Agrostis canina*	do	0	1	0/19	
Agrostis alba	*Agrostis alba*	do	0	1	0/28	

Summary of results of inoculations with *P. graminis agrostis:*

Hosts found naturally infected: *Agrostis alba* L., *A. stolonifera* Vasey.

Easily infected by artificial inoculation: *Agrostis canina* L., *Alopecurus geniculatus* L., *A. pratensis* L., *Bromus tectorum* L., *Dactylis glomerata* L., *Holcus lanatus* L., *Koeleria cristata* (L.) Pers.

Weakly infected by artificial inoculation: *Avena sativa* L., *Calamagrostis canadensis* (Michx.) Beauv., *Hordeum vulgare* L., *Secale cereale* L.

Hosts not infected by artificial inoculation: *Anthoxanthum odoratum* L., *Bromus inermis* Leyss., *Hordeum jubatum* L., *Phalaris canariensis* L., *Triticum vulgare* Vill.

It seems probable that a number of species of Agrostis are hosts for *P. graminis agrostis*, although it was found in the field only on *A. alba* and *A. stolonifera*. The grasses which were easily infected artificially may harbor the rust in nature. It is quite possible that if more trials had been made *Calamagrostis canadensis* would also have proved more susceptible than it appeared to be, because the few leaves which became infected developed fairly normal uredinia. Of the three cereals, barley and oats are most easily infected. The uredinia are, however, always very small and few in number. It seems probable that *Phalaris canariensis*, *Hordeum jubatum*, and *Anthoxanthum odoratum* can be infected by the rust, although the inoculations made thus far have not resulted in successful infection. Negative results from a small number of trials often mean little.

Stuart, as reported by Arthur (7, p. 18), succeeded in infecting wheat with urediniospores from *Agrostis alba vulgaris*, but there is some possibility of error since the spores on wheat were larger than those from the original host. Carleton (7, p. 18) did not succeed in infecting wheat or oats with the rust from *Agrostis alba vulgaris*, and concludes that it is a distinct form. Eriksson gives *Agrostis alba* and *A. stolonifera* as hosts. Jaczewski (18, p. 353) gives *Agrostis alba* as host and states that the rust is also capable of infecting the following:

Secale cereale, Avena sativa, Triticum vulgare, Hordeum vulgare, Triticum repens, Dactylis glomerata, Bromus secalinus, Bromus inermis, Aira caespitosa, Apera Spica venti.

It is quite possible that the rust will be found in nature on a number of grasses. Although it probably occurs commonly in nature, it is doubtful if it is of practical importance on any of the cereals, since it can infect them only very weakly.

GENERAL DISCUSSION.

MORPHOLOGY OF UREDINIOSPORES [1]

In general the size and shape of urediniospores of different biologic forms of *Puccinia graminis* are similar. If, however, large numbers of spores are measured and the arithmetical mean or biometrical mode determined, it becomes quite apparent that there are appreciable and fairly constant differences, provided the spores measured be taken from congenial hosts. Jaczewski (18, p. 358) briefly summarizes the previous observations of similar nature, but states that he was unable to distinguish the different biologic forms in Russia by spores sizes. It can,

[1] Spore measurements were made by Mr. M. N. Levine. Only the dimensions of spores on congenial hosts are given; the other data will be presented in a separate paper.

however, be done if the spores of the various biologic forms are developed on congenial hosts under similar conditions and if enough spores are measured. The range of variability in size of urediniospores is sufficiently great to cause overlapping in some cases unless conditions have been uniform. A brief summary of the important characters of urediniospores of the different biologic forms is given. The sizes are given in Table XXXIV.

P. graminis tritici.—The spores are quite constant in size, shape and color. They are longer than those of any other forms, but in width they are about the same as those of *P. graminis avenae.* Shape is elliptic to ovate, color bright cadmium-yellow.

P. graminis tritici compacti.—Quite similar to *P. graminis tritici.* Color practically the same; spores slightly longer; shape, ovate to ellipsoid.

P. graminis secalis.—Uniform in size, shape and color. Shape elongate-elliptic; in length somewhat shorter than urediniospores of *P. graminis avenae,* in width approaching that of urediniospores of *P. graminis phleipratensis.* Color dull yellow to grayish, similar to that of *P. graminis phleipratensis.*

P. graminis avenae.—Color bright cadmium-yellow; size and shape very variable, shape ellipsoid, pyriform or globose.

P. graminis phleipratensis.—Shape mostly pyriform; color dull yellow to grayish; size fairly uniform.

P. graminis agrostis.—Spores very similar to those of *P. graminis phleipratensis,* possibly not quite so dominantly pyriform and somewhat smaller.

In order to facilitate ready comparison the spore dimensioms are grouped in Table XXXIV.

TABLE XXXIV.—*Comparative sizes in microns of urediniospores of biologic forms of Puccinia graminis*

Biologic form.	Size limits.	Modes.
P. graminis tritici (American form)	23. 04–40. 96×15. 04–24. 96	32. 64×19. 71
P. graminis tritici (Australian form)	25. 92–41. 60×16. 00–21. 76	33. 17×18. 66
P. graminis tritici compacti	24. 96–38. 08×14. 40–25. 28	31. 76×19. 52
P. graminis secalis	17. 92–38. 72×13. 44–21. 44	27. 23×16. 93
P. graminis avenae	19. 20–37. 12×13. 76–25. 60	28. 64×19. 49
P. graminis phleipratensis	16. 00–29. 76×12. 80–21. 12	23. 40×17. 31
P. graminis agrostis	17. 60–28. 48×13. 76–18. 88	22. 72×16. 16

It will be readily seen from Table XXXIV that there is considerable difference in the sizes of urediniospores of different biologic forms. Those of *P. graminis tritici* are largest and those of *P. graminis tritici compacti* differ only slightly. All the other forms are quite different, however, the spores of both *P. graminis avenae* and *P. graminis secalis* being shorter,

while those of the remaining two forms are very much smaller. The spores of the *avenae* and *secalis* forms do not differ greatly in length, but the spores of the form *avenae* are considerably thicker than those of the form *secalis*. The spores of the form *agrostis* are smaller than those of the form *phleipratensis*, especially in width.

APPEARANCE AND DEVELOPMENT OF UREDINIA

The general appearance of the uredinia of different biologic forms of stemrust on congenial hosts is, with minor exceptions, quite similar. The linear uredinia of *P. graminis phleipratensis* are, of course, distinctive, but even this character is not constant. The shape of uredinia on congenial hosts is usually oval or somewhat broadly linear, although, when heavy infection occurs, the uredinia may coalesce to such an extent that the identity of the individual uredinia is almost lost. The length varies from only 1 or 2 mm. to 0.5 cm. or more. The color is quite variable. Usually when the relative humidity is high or the light intensity low the color tends to become paler. On some hosts the epiderm is raised before the uredinia break out, giving the plant a blistered appearance in the infected area. The torn edges may persist for some time after the epiderm has been ruptured. Again, this appearance may be entirely absent.

The size, shape, and color of uredinia may vary greatly on semicongenial or uncongenial hosts. Very often the uredinia become rounder and very much smaller on such hosts. The color may also vary a great deal, so much, in fact, that it is sometimes necessary to transfer the rust back to the original host in order to become convinced that something has not gone wrong. Carleton (7, p. 16) long ago called attention to this fact, and it has been a matter of common observation since then. Of course, such differences are to be expected, just as one expects phanerogamic plants to vary with the conditions under which they are grown; but with the rusts this variation emphasizes the necessity of determining the performance before the identity can be established.

The incubation period of the various forms varies considerably on the same host. The age of the plant, the vegetative condition of the plant, the temperature, and the light intensity may affect the rate of development of the rust materially. The cereals are usually susceptible at any age up to ripening time. The susceptibility of some grasses, however, under greenhouse conditions at least, seems to vary more. No careful experiments were made to investigate this question thoroughly, but repeated observations were made under conditions which made accurate comparisons possible. Some plants, such as some species of Agropyron and Elymus, are extremely susceptible when young and much less so when older. In fact no infection, or at best very weak infection, occurred on some of these grasses when they were about 3 months old; while,

when they were only a week or two old, they became very heavily infected when inoculated with the same rust. Some of these same grasses, however, became infected under natural conditions in the field when quite old. Other grasses, such as *Phleum pratense* and *Agrostis alba*, seem to be more susceptible when they are older. It was often difficult to obtain normal infection on very young plants, while on older plants very heavy infection resulted from inoculations made under similar conditions. Other grasses again, such as *Dactylis glomerata*, seem equally susceptible at all ages. Whether these observations are of any significance can only be determined by carefully controlled experiments made on an extensive scale under varying conditions and with a large number of species of plants and different forms of rust. It seems quite possible that they may explain conflicting results obtained by the same investigators and possibly the discrepancies reported by different investigators. In fact, if the results of investigations by various workers are to be comparable, methods should be standardized with respect to kinds and ages of plants used as well as mechanical methods.

Temperature is important in determining the rate of development of the various biologic forms. No distinct differences were noted between the different forms; such differences, however, may have escaped observation. Contrary to a fairly general belief, stemrust seems to develop best at fairly high temperatures, provided conditions have been favorable for infection. The best infection usually results when the temperature is low enough to cause the condensation of moisture in a very fine film on the leaves. This usually occurs at night. Then, infection having taken place, the uredinia seem to develop more rapidly at higher temperatures up to a certain point, probably about 75° F. During extremely hot weather it is difficult to secure heavy infection, probably on account of the difficulty of inducing a film of water to form on the inoculated plants and on account of the effect of the heat on the vigor of the plants. Low temperatures, below about 65° F., also inhibit the development of the rust.

A considerable amount of sunlight is necessary for the best development of rust. Whether the effect is direct or indirect, the writers are unable to say. During periods of cloudy weather, however, the incubation period may be lengthened a week or more, and the rust does not develop so abundantly as during bright weather, as experiments to determine this showed. Plants were inoculated under the same conditions, placed under bell jars for the same length of time and kept side by side, except that some were partially shaded and the others kept in direct sunlight. The shaded plants invariably were more weakly infected than the others. Partially etiolated plants were infected with difficulty and the rust developed very weakly on them. No rust developed on etiolated plants. Careful and extensive experiments are desirable.

PARASITISM OF BIOLOGIC FORMS

The parasitism of some of the biologic forms is surprisingly similar. Often the reaction of only one or two host plants distinguishes one form from another. By reference to Tables XXVIII to XXXIII it is quite apparent that *P. graminis tritici*, *P. graminis tritici compacti*, and *P. graminis secalis* fall naturally into one group, so far as parasitism is concerned. In the same way *P. graminis avenae*, *P. graminis agrostis*, and *P. graminis phleipratensis* fall into another.

There are a number of common hosts for *P. graminis tritici*, *P. graminis tritici compacti*, and *P. graminis secalis*. From the results thus far obtained it is very evident that a number of species of the genera Agropyron, Elymus, and Hordeum are about equally congenial hosts for these three biologic forms. The first two can be distinguished from each other definitely, so far as present knowledge goes, only by their action on *Triticum vulgare*, while *P. graminis secalis* differs from both in its effect on *Secale cereale* and *Agropyron repens*. These differences are, however, very distinct and apparently quite constant. The matter of the constancy of the forms will be dealt with fully in a subsequent paper.

P. graminis avenae, *P. graminis agrostis*, and *P. phleipratensis* are also similar parasitically. *Koeleria cristata*, *Holcus lanatus*, *Alopecurus pratensis*, *A. geniculatus*, and *Dactylis glomerata* are common hosts for all three. *P. graminis agrostis* and *P. phleipratensis* attack *Avena sativa* in about the same degree. The infection is always weak, the uredinia nearly always being very minute. *Hordeum vulgare* and *Secale cereale* are infected weakly by all three. Exhaustive experiments on these three forms are very desirable and may yield interesting results.

All of the biologic forms studied can develop, at least to a limited extent, on *Hordeum vulgare*, *Secale cereale*, and possibly on other hosts. The degree of infection varies widely, however, as previously noted.

RELATION OF WILD GRASSES TO RUST EPIDEMICS

From a practical standpoint the effect of the wild grasses on cereal-rust epidemics is important. The influence of the grasses would seem to be possibly significant in three ways: (1) In permitting the overwintering of the rust in the mycelial or urediniospore stage, (2) in aiding in the dissemination of rust, and (3) in possibly breaking down the specialization of the biologic forms in nature.

The writers have done preliminary work on the overwintering of rust on wild grasses, but are not prepared to draw definite conclusions. Certainly urediniospores of *P. graminis phleipratensis* can survive the winter in some localities. Johnson (19, p. 12–13) showed this to be true at Arlington, Va., and Hungerford (17) showed the same to be true in Wisconsin. Mercer (21) states that in North Dakota urediniospores of timothy rust are hard to find after the first hard freeze. Observations

made by the writers at St. Paul, Minn., in the winter of 1916–17, an unusually severe one, indicate quite clearly that the urediniospores survive the winter quite easily in Minnesota. A summary of the experiments made on the overwintering of various cereal rusts is given by Freeman and Johnson (14, p. 45–53), who also found that *P. graminis* and probably *P. rubigo-vera* could survive the winter in the uredinial stage at St. Paul, Minn. Bolley and Pritchard (4, p. 642) had previously shown this to be true for *P. rubigo-vera* in a number of regions. From preliminary observations it seems quite probable that urediniospores of *P. graminis* are injured by heat and drying more than by low temperatures. If this is true, the extent to which the rust overwinters may depend on the amount of rain in the fall and on the amount of snow in the winter. It would be very interesting to make extensive observations in regions of high altitude, where snow comes early. Abundant urediniospores occur on various grasses in the fall when the snows begin, and it is possible that in such regions overwintering is very common. Further investigations are needed.

There can be little question that grasses aid very materially in the dissemination of rust. Enormous numbers of urediniospores are developed on grasses, and these are undoubtedly blown long distances by the wind. Whether the grasses are important in initiating the early spring infections, however, is another matter. If the uredinial stage of the rust persists on grasses throughout the winter, they probably are responsible for much of the early infection. Even if such overwintering is of infrequent occurrence, however, grasses may still be important because they usually are nearer barberries than grain fields are. They may become infected, develop urediniospores in a week or 10 days, and these may then blow to other grasses or cereals and thus spread during the entire growing season.

An excellent summary of observations on the effect of barberry on surrounding cereals and grasses is given by Freeman and Johnson (14, p. 28–45) and by Pritchard (22, p. 169–175) and need not be repeated here. Pritchard (22, p. 179–181), as a result of experiments in North Dakota, concludes that barberry plants have but little effect in starting rust epidemics in the spring, because—

> *P. graminis* probably appeared upon the experimental plot of winter wheat almost or quite as early as upon *Agropyron repens* and *Hordeum jubatum* even when the latter were in the immediate vicinity of the barberry. * * * With the exception of the one case mentioned under date of June 27, the uredospores of *P. graminis* were generally present upon the spring wheat earlier than they were observed upon the wild grasses remote from the barberry bushes.

He states further—

> that one form of *P. graminis* is common to *Hordeum jubatum*, *Agropyron tenerum*, *A. repens*, *Avena fatua*, oats, and rye, but is incapable of infecting either barley or wheat. This furnishes little encouragement to those who believe that *P. graminis*

is spread to the wheat fields from the barberry bushes or from occasional protected spots, as beneath ice, by the aid of the native grasses.

The experience of the writers does not agree entirely with that of Pritchard. As mentioned previously, the writers are in doubt as to the importance of the overwintering of the uredinial stage on grasses. But observations made in Minnesota for the past few years indicate that barberries may be important, at least locally.

In 1914 numerous well-developed æcia of *P. graminis secalis* were found on barberry growing near Lake Minnetonka, Minn., as early as May 17. Successful infection was repeatedly obtained on rye and barley, but not on wheat or oats. At this time there was no rust on barley or rye in the region, but *Agropyron repens* near the barberries soon became heavily rusted. New æcia continued to be developed at irregular intervals until July 10 and possibly longer. Pycnia began to appear on barberries on University Farm, St. Paul, on May 18 and by May 22 æcia had formed. Wheat, oats, barley, and rye were inoculated with the æciospores on May 23, and wheat and barley became infected, while oats and rye did not, showing that the rust was *P. graminis tritici*. Æcia developed in great abundance on another group of barberries on University Farm about May 20. By June 9 volunteer rye, *Agropyron repens*, and *Hordeum jubatum* near these barberries had become very severely rusted. Inoculations made with both æciospores and the urediniospores showed that both *P. graminis secalis* and *P. graminis tritici* were present. Most of the rust was *P. graminis secalis*. At this time grasses and wheat at some distance from the barberries were not at all rusted. Winter wheat near barberries was beginning to rust.

In 1915 viable æciospores were obtained at University Farm on May 8. These proved to be *P. graminis tritici*. Successive crops of æcia were produced until about July 1, and, as in the previous year, both near these barberries and others bearing æcia of *P. graminis secalis*, grasses and cereals, when these were growing near, rusted severely while those at some distance remained free for about a month, when the rust began to appear quite generally on grasses. On July 10, at Dickinson, N. Dak., *Agropyron repens*, *A. tenerum*, and *Hordeum jubatum* were found very badly rusted near a group of barberries, while the same grasses and wheat half a mile away were just beginning to rust. On July 12, at Jamestown, N. Dak., *Hordeum jubatum* was found badly rusted near a field of Marquis wheat which was just beginning to rust slightly. A few miles away *A. smithii* was literally covered with urediniospores; in fact, the ground was red with them, and a field of wheat next to the grass was just beginning to rust. No barberries were seen, because lack of time prevented a search on farmsteads near by. The observations merely emphasize the fact that grasses do sometimes rust before cereals, and that the rust may spread from them to the cereals.

Æcia did not appear on barberries as early in 1916 as in 1915, owing probably to the late spring. Very heavy infection of barberries with *P. graminis secalis* was observed in Hennepin County, Minn., on May 26, and a few days later æcia of *P. graminis tritici* were found. By June 15 æcia were abundant in many localities. New æcia continued to be developed until well into July. The unusual number of æcia was very noticeable. Barberry bushes were often rendered unsightly on account of the severity of rust attack. By July 5 rust was becoming fairly abundant on many grasses, and a number of cases were observed where various grasses were severely affected, while wheat, barley, and rye near by were just beginning to develop a moderate amount of rust. This was especially true of *Hordeum jubatum*, which, on account of its habit of growth, furnishes very favorable conditions for infection.

The above observations show that grasses, at least in Minnesota, often become severly rusted near barberries in the spring or early summer before rust is present to any extent elsewhere. It seems quite probable that the urediniospores may be blown considerable distances by the wind and may infect other grasses and cereals. While the writers do not wish to be understood as maintaining that the sequence of barberry to grass to cereal is responsible for general rust attacks, it is not at all improbable that locally this may be very important. While it is true that the percentage of viable æciospores is often low, nevertheless sufficient numbers germinate to cause heavy epidemics on grasses early in the season. The possibility of transfer from the grasses or from the barberries directly to cereals depends, of course, on the biologic form present. *P. graminis tritici* and *P. graminis secalis* are often found on the same barberries; and *P. graminis avenae* is not uncommon. Fortunately this phase of the rust problem is being attacked vigorously by the Office of Cereal Investigations, United States Department of Agriculture.

SUMMARY

(1) *Puccinia graminis* has been collected on about 35 species of grasses in the upper Mississippi Valley, a part of the Northern Great Plains region, and a small area of the Pacific Northwest.

(2) Inoculation experiments with the rust from about 30 grasses were made and the following biologic forms were isolated: *Puccinia graminis tritici, P. graminis tritici compacti, P. graminis secalis, P. graminis avenae, P. graminis phleipratensis*, and *P. graminis agrostis*.

(3) *P. graminis tritici compacti* was found only in the Palouse country of Washington and Idaho; it occurs on club wheat and grasses which, east of the Rocky Mountains, are hosts for *P. graminis tritici*. No ordinary *P. graminis tritici* was found west of the Rocky Mountains.

(4) More than one biologic form may occur on the same host in nature, sometimes even on the same plant. In such cases it is necessary to

employ differential hosts to determine the identity of the forms. *P. graminis tritici* and *P. graminis secalis* have been found associated most often.

(5) Different strains of the same bioligic form sometimes differ in virulence on the same hosts; but the differences are usually in degree only.

(6) There seems to be no sharp geographical specialization of biologic forms in the upper Mississippi Valley and Northern Great Plains area, where the biologic forms are quite uniform.

(7) On the basis of parasitism the biologic forms can be divided into two groups: (1) *P. graminis tritici*, *P. graminis tritici compacti*, and *P. graminis secalis;* (2) *P. graminis avenae*, *P. graminis phleipratensis*, and *P. graminis agrostis.*

(8) Wheat, club wheat, rye, and *Agropyron repens* are differential hosts for group 1. The *tritici* form infects wheat and club wheat readily and rye and *A. repens* weakly; the *tritici compacti* form attacks club wheat readily and the other three weakly; the *secalis* form develops normally on rye and *A. repens*, but very rarely attacks the other two. All three develop well on barley, *Hystrix patula*, and *Bromus tectorum* and on a number of species of Agropyron, Elymus and Hordeum.

(9) Differential hosts for the forms in group 2 are oats, *Phleum pratense*, and *Agrostis* spp. The *avenae* form develops normally on oats, infects *Phleum pratense* weakly, and develops fairly well on *Agrotis alba;* the *phleipratensis* form grows normally on *Phleum pratense*, infects oats rather weakly, and has not yet infected *Agrostis alba;* the *agrostis* form develops normally on *Agrostis* spp., infects oats very weakly, and has not yet infected *Phleum pratense.* All three infect barley and rye weakly, but develop well on *Koeleria cristata*, *Holcus lanatus*, *Dactylis glomerata*, *Alopecuris geniculatus*, and *A. pratensis.*

(10) Barley, rye, and *Bromus tectorum* have been infected by all six biologic forms. Oats have been infected by all but *P. graminis tritici compacti*, but not enough trials have been made with this form.

(11) All gradations in susceptibility occur, from complete immunity to complete susceptibility to various biologic forms. The following reactions may be made to inoculation: No visible effect; appearance of small flecks; production of very minute uredinia without any flecks; production of minute uredinia in either small or large dead areas; development of moderately large uredinia in small, medium, or large flecks; production of large uredinia surrounded by small dead areas or by apparently healthy tissue.

(12) The biologic forms can be distinguished from each other morphologically as well as parasitically. The size, shape, and color of the urediniospores are the distinguishing characters. The determination of biometrical modes permits identification with a reasonable degree of cer-

tainty if the spores measured have been developed under approximately similar conditions.

(13) The rate of development of a given biologic form depends on the vigor of the rust strain, the kind, and sometimes the age of the host plant, the amount of light, heat, and humidity. Sunlight, high relative humidity, and moderate temperatures, up to about 75° F., are favorable to rust development.

(14) Preliminary observations were made on the overwintering of the uredinial stage on grass hosts, but definite conclusions have not been reached, except for *P. graminis phleipratensis* which survived the very severe winter of 1916–17 at St. Paul, Minn., very easily.

15) There is evidence to show that grasses often rust in the spring or early summer before rust appears in grain fields in the same vicinity. This is especially true if grasses are near barberries. The rust thus developed early in the season has usually been the rye and wheat stemrust forms.

(16) Inconceivably large numbers of urediniospores are produced by various grasses in cereal-growing regions. Unquestionably, therefore, grasses are very important in increasing the amount of infective material and in this way, if in no other, they are important in the cereal-rust problem.

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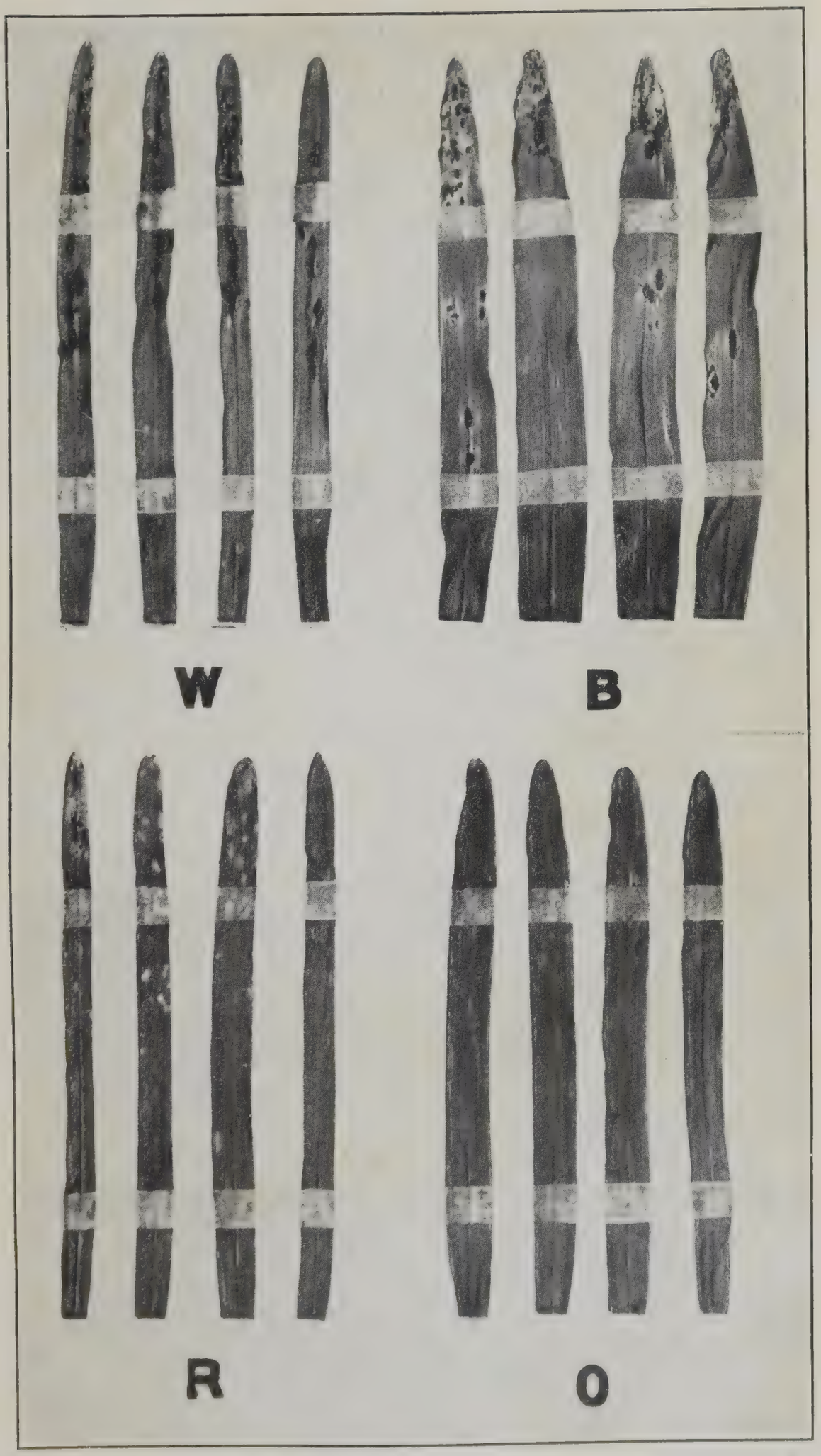
PLATE 53

Puccinia graminis tritici on wheat (*W*), barley (*B*), rye (*R*) and oats (*O*) 11 days after inoculation. Normal uredinia on wheat and barley; small uredinia and sharp flecks on rye; no infection on oats.


W
B
R
O

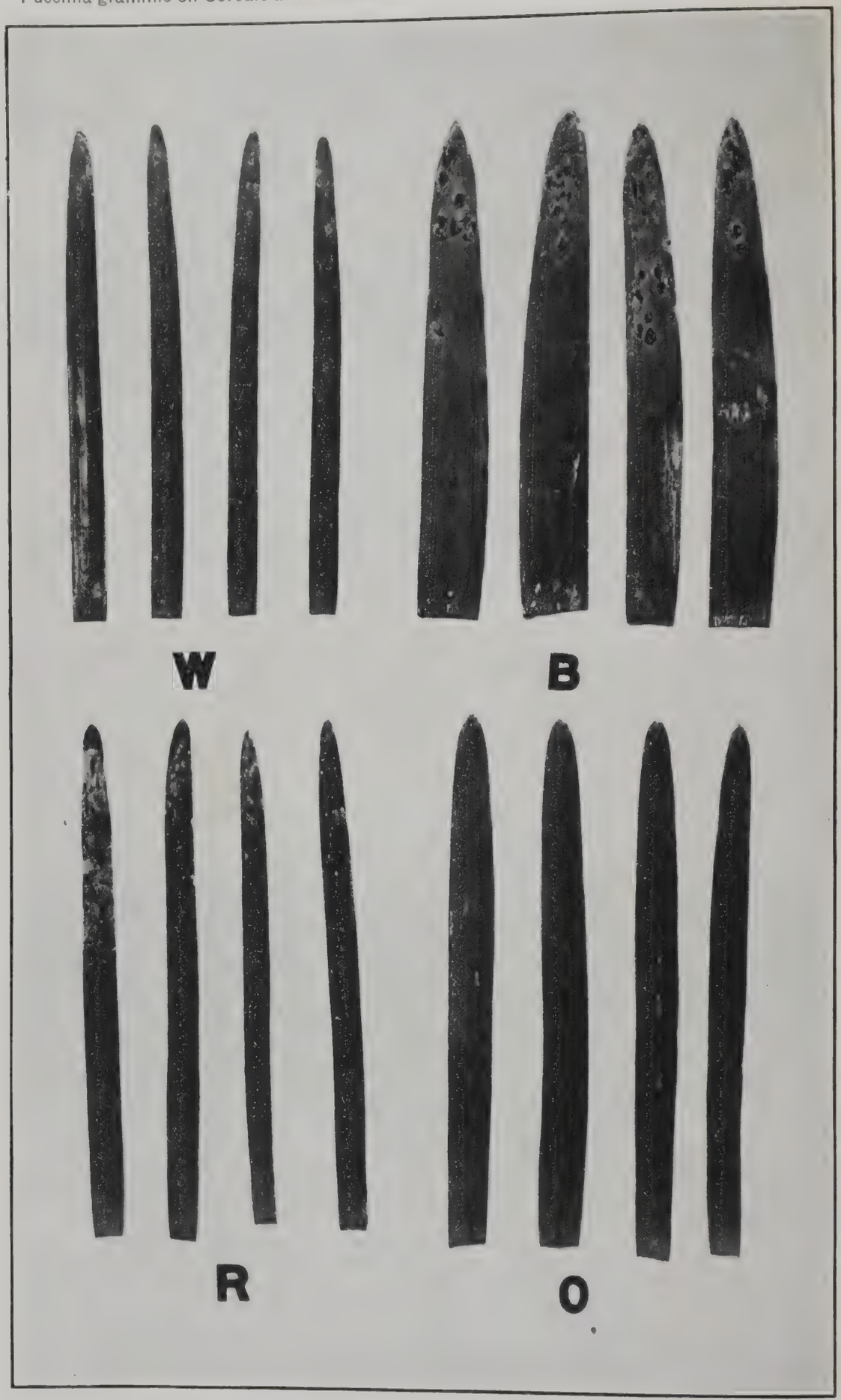

W
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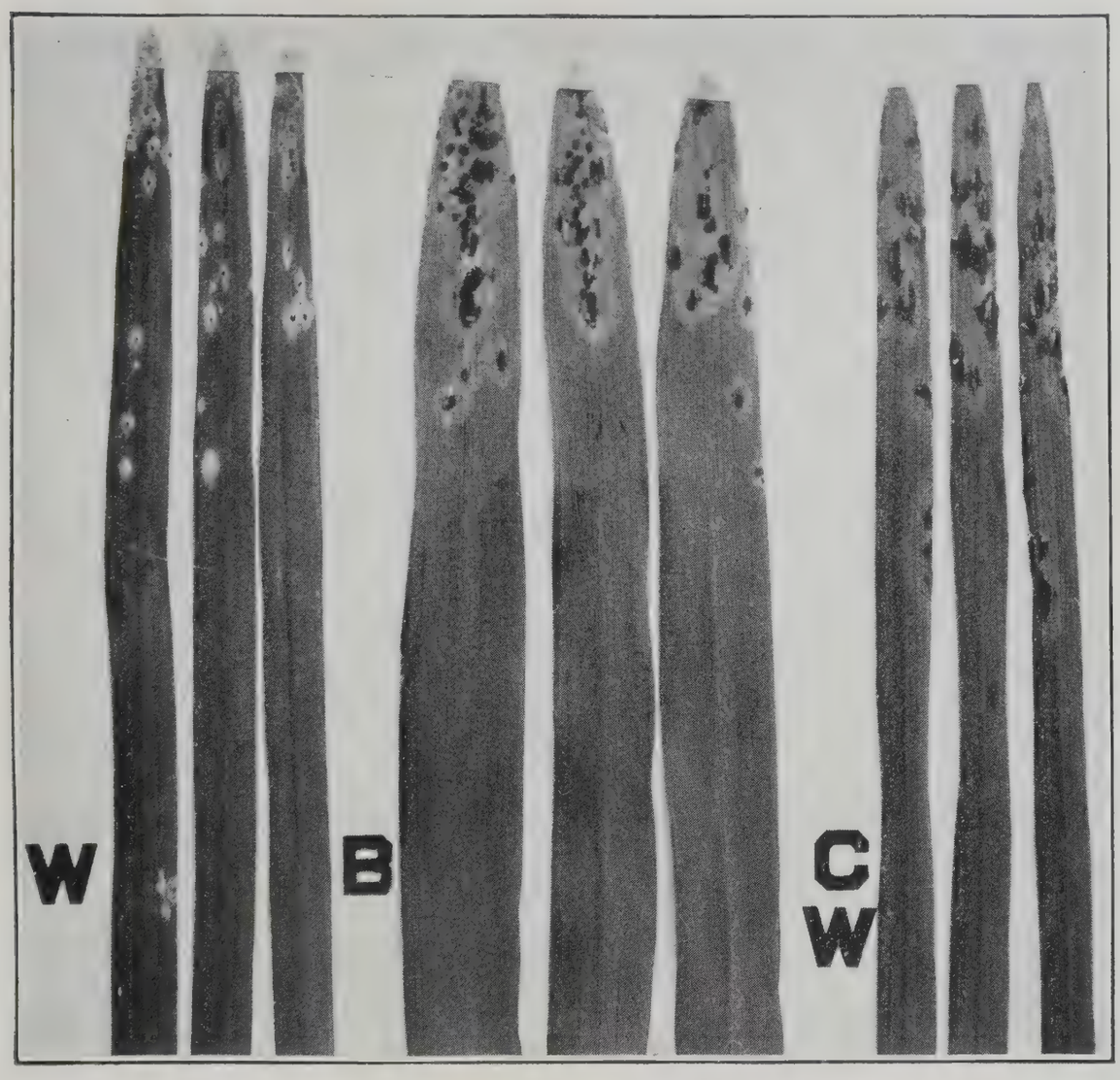
PLATE 54

Puccinia graminis tritici compacti on wheat (*W*), barley (*B*), rye (*R*), and oats (*O*) 10 days after inoculation. Very small uredinia in sharp dead areas on wheat; normal development on barley; small uredinia and distinct flecks on rye; no infection on oats.

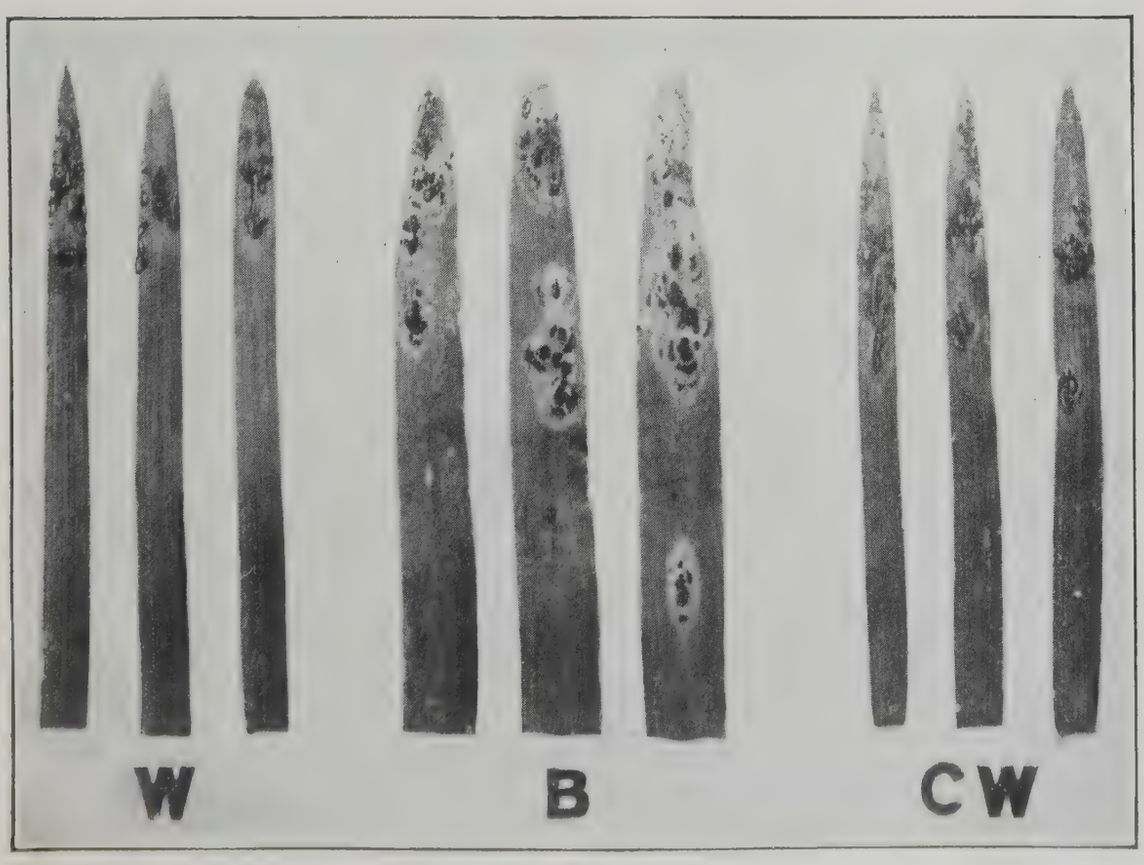
PLATE 55

A.—*Puccinia graminis tritici compacti* on *Triticum vulgare* (*W*), barley (*B*), and *Triticum compactum* (*CW*)—that is on common wheat, barley, and club wheat. Normal development on barley and club wheat, common wheat showing minute uredinia and hypersensitiveness as indicated by sharp flecks. Compare with figure B.

B.—*Puccinia graminis tritici* on *Triticum vulgare* (*W*), barley (*B*), and *Triticum compactum* (*CW*)—that is, on common wheat, barley, and club wheat. Normal development on all three cereals. Compare with figure A.



A



B

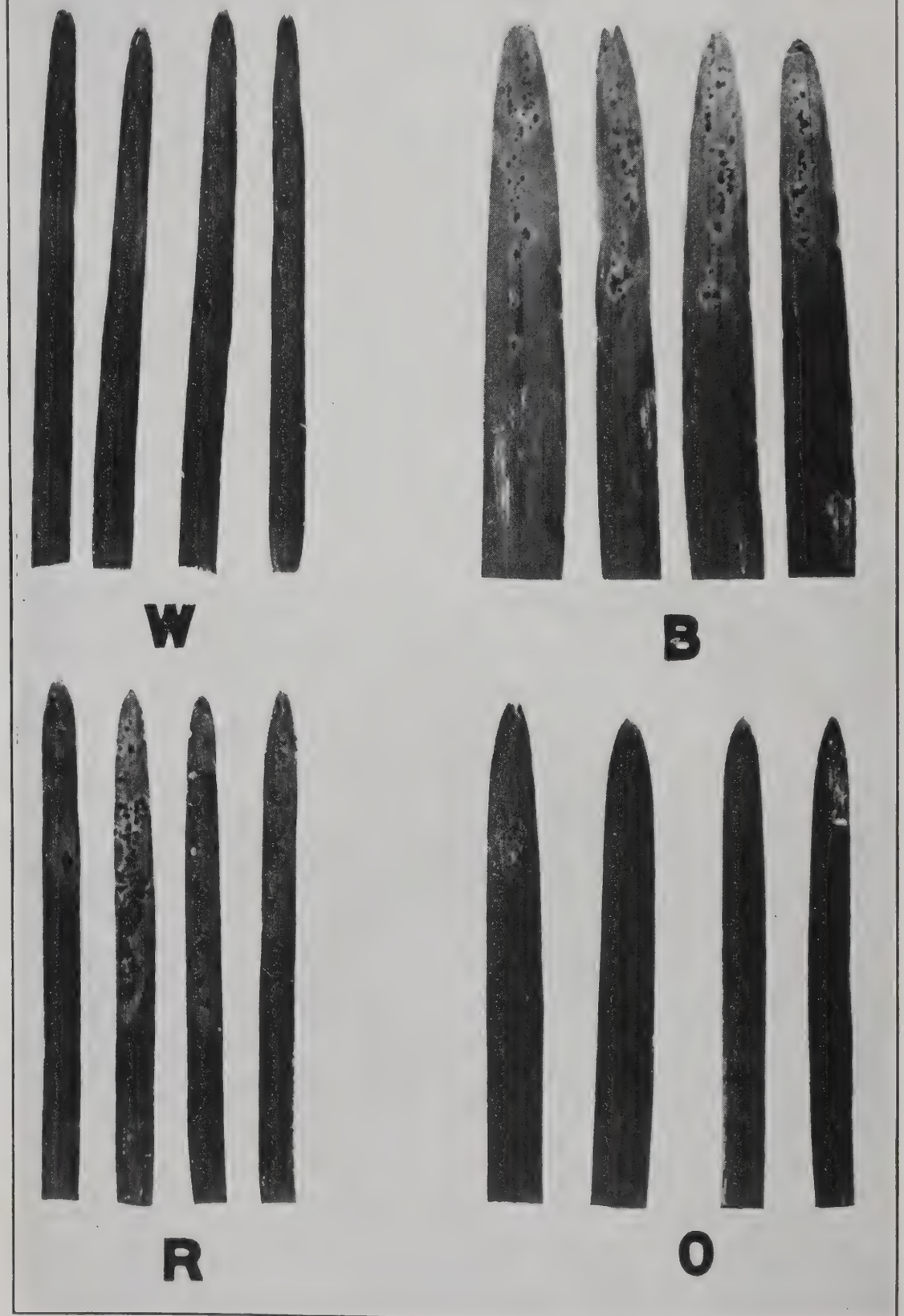
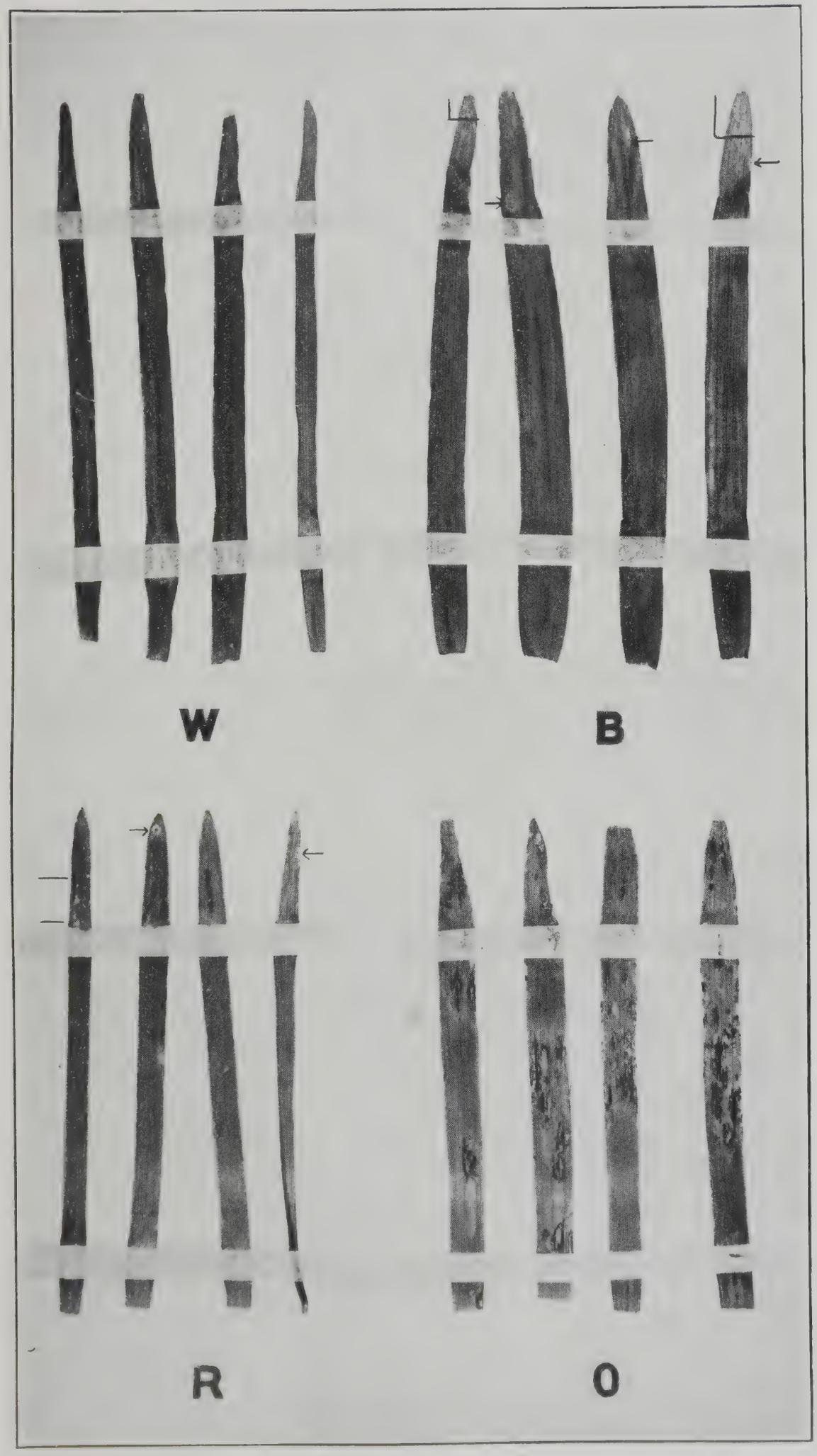

W
B
R
O

PLATE 56

Puccinia graminis secalis on wheat (*W*), barley (*B*), rye (*R*), and oats (*O*). Normal but rather weak development on barley and rye. No infection on oats and wheat. (Very small uredinia are rarely produced on wheat and oats.) Twelve days after inoculation.

PLATE 57

Puccinia graminis avenae on wheat (*W*), barley (*B*), rye (*R*), and oats (*O*). Normal development on oats; small uredinia in very small, dead areas on barley and rye (location of single uredinia indicated by arrows; groups between lines); no infection on wheat. Ten days after inoculation.


W
B
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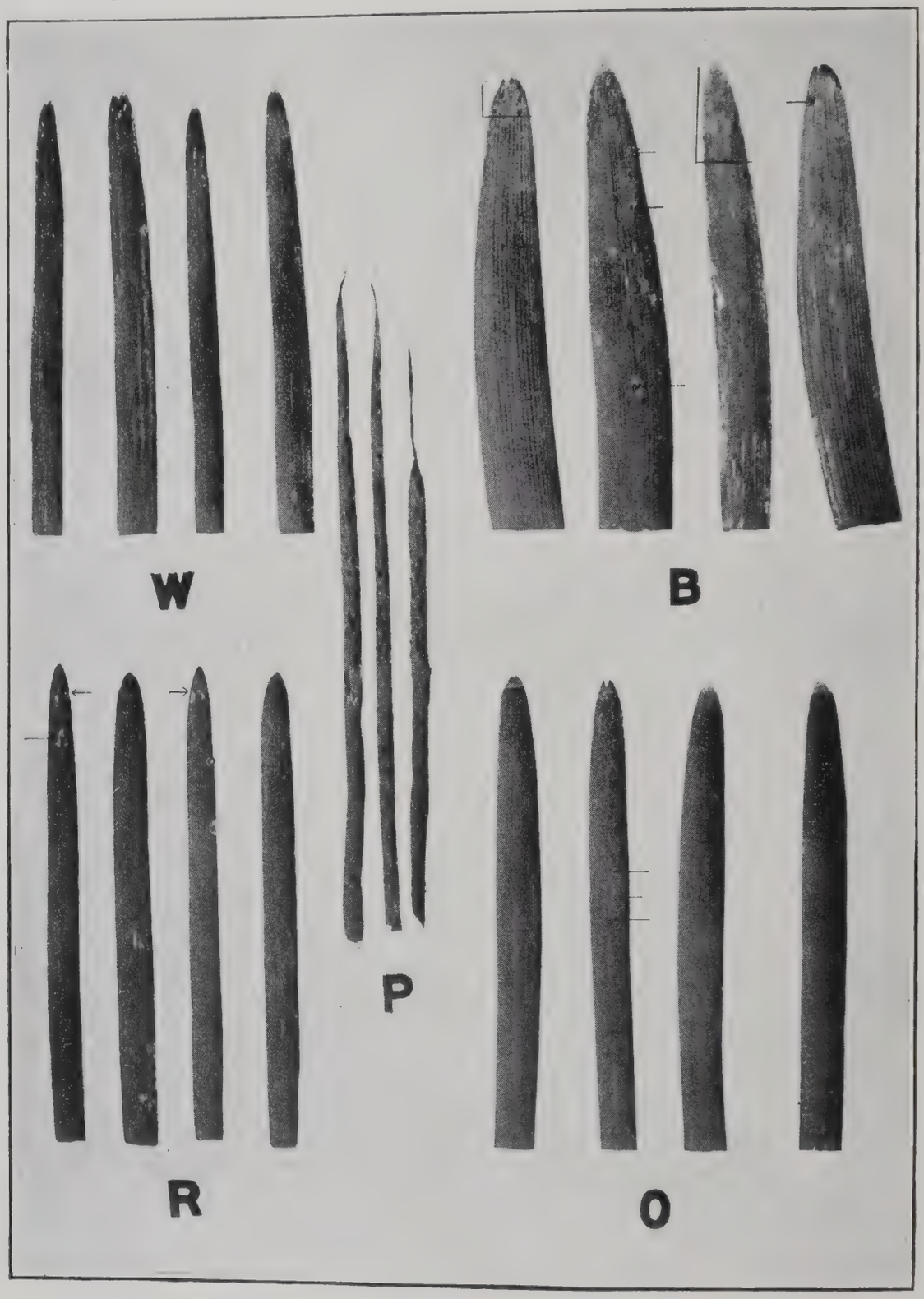
O


W
B
P
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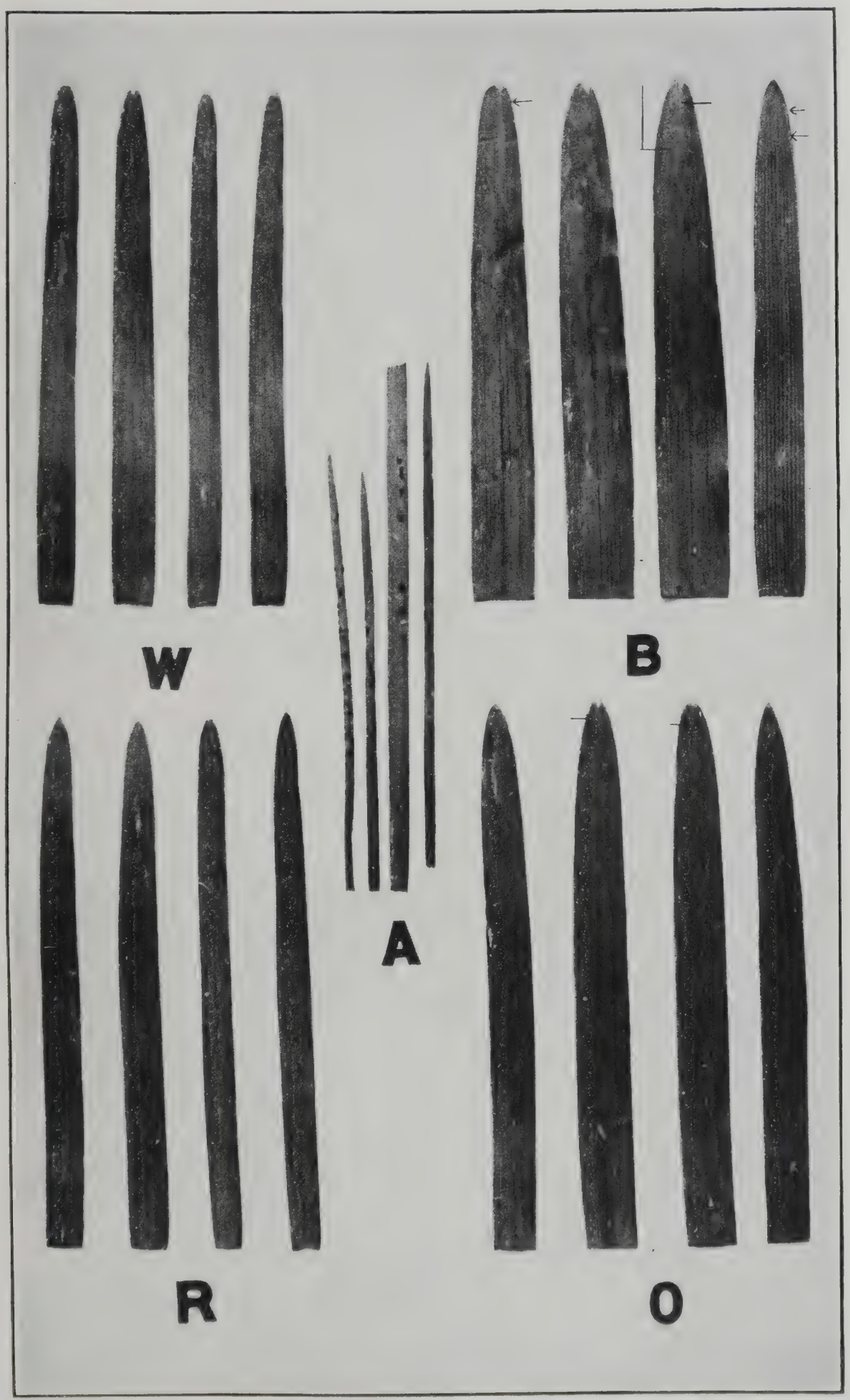
O

PLATE 58

Puccinia graminis phleipratensis on wheat (*W*), barley (*B*), rye (*R*), oats (*O*), and *Phleum pratense* (*P*). Normal development on *Phleum;* small uredinia on barley, rye, and oats (location shown by arrows or lines); some flecks without uredinia on barley and rye; no infection on wheat. Fourteen days after inoculation.

PLATE 59

Puccinia graminis agrostis on wheat (*W*), barley (*B*), rye (*R*), oats (*O*), and *Agrostis alba* (*A*). Minute uredinia on barley and oats; normal infection on *Agrostis alba;* no infection on wheat or rye (rye is sometimes weakly infected).


W
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QUASSIA EXTRACT AS A CONTACT INSECTICIDE

By N. E. McINDOO, *Insect Physiologist, Deciduous Fruit Insect Investigations, Bureau of Entomology,* and A. F. SIEVERS, *Chemical Biologist, Drug-Plant and Poisonous-Plant Investigations, Bureau of Plant Industry, United States Department of Agriculture*

INTRODUCTION

According to the literature, it appears that the extract from the Jamaica quassia wood (*Picrasma excelsa* Swz.) when properly extracted and applied is an efficient and satisfactory insecticide for the hop aphis (*Phorodon humuli* Schr.); but, owing to the fact that the active constituent of quassia wood is not toxic in the usual sense, authorities on insecticides are not yet agreed concerning the efficiency of quassia extract. Since this extract has never been used extensively upon other species of aphids, it is desirable to know whether or not it may be employed as a general insecticide for all aphids. Before being able to determine this point for aphids in general, it is first necessary to make a careful study of the economic methods of the extraction of quassia wood in order to determine what process assures the most thorough extraction of such constituents as are found by means of tests on aphids to be the toxic principles. It is further necessary to observe the physiological effects of this poisonous substance upon aphids. In this investigation, therefore, two chief objects have been kept in view: (1) To determine the efficiency of various extracts of quassia wood, and (2) to study the pharmacological effects of these extracts upon insects.

HISTORICAL REVIEW

1.—LITERATURE DEALING WITH QUASSIA AND QUASSIIN

According to the Ninth Decennial Revision of the United States Pharmacopœia, official quassia is derived from either *Picrasma excelsa* (Swz.) Planch. (family Simarubaceae), known commercially as Jamaica quassia, or from *Quassia amara* L. (family Simarubaceae), known commercially as Surinam quassia. According to the literature, there are a number of other plants which furnish wood with similar characteristics, whose active constituent is identical with, or similar to, quassiin, the bitter principle and main constituent of official quassia. These plants

are as follows: *Quassia simaruba*, *Quassia excelsa*, *Quassia polygama*, *Pitcarnia excelsa s. amara*, *Picraena excelsa*, *Picrasma quassioides*, *Picrasma eilantoides*, *Ailanthus excelsa*, *Simaruba amara*, *Simaruba cedron*, and *Simaruba versicolor*. There is hardly a question, however, that some of these are derived from the same source.[1]

According to Flückiger and Hanbury (13),[2] quassia was introduced commercially into Europe about the middle of the eighteenth century. At first it was obtained entirely from *Quassia amara*, but later, owing to the great demand, it was obtained largely from *Picrasma excelsa*, the Jamaica quassia, a much larger tree than *Quassia amara*.

Dujardin and Égasse (6) state that *Simaruba amara* was introduced into France in 1713 as a remedy for dysentery. One of the earliest writers to mention quassia as an insecticide was Brande (3), who, in 1825, stated that it was an effectual stomach poison for flies when used in the form of an infusion sweetened with brown sugar.

As early as 1779 Paarmann (31) wrote a review on quassia and its uses. With respect to the anthelmintic properties of the bitter principle, he concurs in the opinion of others that its action on intestinal worms is due to a stimulation of the intestinal secretion which prevents their development rather than to any directly poisonous effect. He also performed some experiments on the extraction of quassiin by various methods.

In 1794 Lindsay (21) published an account of *Quassia polygama* which he claimed had long been used in Jamaica as a useful medicine in "putrid fevers." All parts of the plant except the pulp of the fruit are bitter. At that time large quantities were being exported to England for use in the brewing of ale and porter.

In 1796 Trommsdorff (45) conducted a series of experiments from which he concluded that the best way to extract quassia is to soak the finely chipped wood for some time in cold water and then boil it three times, each time with 12 portions of fresh water. In 1811 Pfaff (34) compared the wood and bark of *Pitcarnia excelsa s. amara*, and concluded that the bark is much more bitter than the wood. He found that cold water extracts the bitter principle entirely and that if the

[1] Several of these names are synonyms; others were incorrectly given in the papers cited. *Picrasma excelsa* Planch. (1846) and *Picraena excelsa* Lindl. (1838) are names of the tree described originally as *Quassia excelsa* Swz., which is now referred to the genus *Aeschrion*, established by Vellozo at an earlier date (1827), and becomes *Aeschrion excelsa* (Swz.) Kuntze. *Quassia simaruba* L. f. is a synonym of *Simaruba amara* Aubl. *Quassia polygama* Lindsay is referred to *Aeschrion excelsa* (Swz.) Kuntze. "*Pitcarnia excelsa s. amara*," published by Pfaff, is an error in the paper cited. There is no genus Pitcarnia; Pitcairnia, for which it may have been intended, is the name of a bromeliaceous genus allied to the pineapple, having nothing in common with the family Simarubaceae, to which the quassia-yielding plants belong. The author may have intended the name for *Picraena excelsa*, and the supposed synonym *amara* for *Simaruba amara*. *Picrasma quassioides* Benn. is a valid name; *P. ailanthoides* (Bunge) Planch. (not *P. eilantoides* as given in the paper cited) is supposed to be a synonym of it. *Ailanthus excelsa* Roxb. is the valid name of an Asiatic tree delightfully aromatic and very different from our ill-smelling *Ailanthus glandulosa* Desf. *Simaruba cedron* is an erroneous name, intended for *Simaba cedron* Planch. *Simaruba versicolor* St. Hilaire is a valid name.—W. E. Safford, Economic Botanist, Bureau of Plant Industry.

[2] Reference is made by number to "Literature cited," p. 528–531.

material is "rubbed," the solvent action of the cold water is greater than that of either hot or boiling water, the high temperature in the case of the latter resulting in an oxidation and consequent insolubility of the bitter principle.

In 1822 Morin (25), working with the bark of *Quassia simaruba*, reported the presence of quassiin and a volatile oil having an odor of benzoin.

In 1829 Fechner (10) came to the conclusion that "rubbing" facilitated the extraction of quassiin from *Quassia excelsa* and that boiling is of no benefit. In 1835 Winckler (48) made an exhaustive study of *Quassia amara*, contributing much to the information already acquired concerning quassiin. He considered quassiin to be of a basic nature, but later investigators proved that it is not a true base. The experiments of Kellar (19) in the same year, while not conclusive, raised the question as to whether quassia contained an alkaloid. Two years later Wiggers (47) pointed out that quassiin was of a nonbasic character. He also outlined in general the properties of quassiin, including its solubility in water, which he found to be 0.45 part in 100. This seems to be much greater than the actual solubility, but his results may have been influenced by impurities, which he himself claimed will increase solubility. The substance obtained he called "quassit," the ending "it" being used to indicate its nonbasic character.

In 1858 Rochelder (38) recorded the fact that both *Simaruba amara* and *Simaruba cedron* contain a crystallizable bitter principle similar to quassiin. In 1868 Enders (9) asserted that quassia was used as a substitute for hops in brewing. In his study he found quassiin to be almost insoluble in water, readily soluble in alcohol and chloroform, and insoluble in ether. He concluded that the toxic principle was not a glucosid and found that it was precipitated by tannic acid.

In 1882 Christensen (4) obtained 12 gm. of what he considered pure quassiin from 18 kgm. of *Picraena excelsa*. This is equivalent to a solubility of 1 to 1,500. The solubility in warm water was found to be less than that in cold water.

In 1884 Oliveri and Denaro (26–29) undertook experiments to determine the molecular structure of the quassiin molecule. In 1889 Dymock and Warden (7) investigated *Picrasma quassioides*, a native of China and the subtropical Himalayas, and found the bark and wood to be as bitter as quassia. A crystallizable principle was isolated which resembled quassiin. An alcoholic extract gave positive reactions with alkaloidal reagents. No pharmacological effects were found. In 1890 Dymock, Warden, and Hooper (8) in their Pharmacographia Indica quote Stewart as stating that the wood of *Picrasma quassioides* was used in the Punjab to kill insects. In the same year Massute (23) published his researches on the chemical constituents of *Quassia amara* and

Picraena excelsa. He studied various methods of extracting quassiin and "picrasmin," as he called the bitter constituent of *P. excelsa*. In 1891 Shimoyama and Hirano (40) described *Picrasma ailantoides* Planch. They found a crystalline principle in the bark which corresponded to quassiin. Four years later Merck (24) separated a substance which he called "quassol" from impure quassiin by solution in ether. Its melting point was found to be 149° to 150° C., while that of pure quassiin is 210° to 211°. It is further distinguished from quassiin by its tastelessness. In the same year Hooper (16) obtained from *Ailanthus excelsa* an extremely bitter substance resembling quassiin. According to Dragendorff (5), *Simaruba excelsa*, a Brazilian species, is used as a remedy for intestinal worms and for skin parasites.

According to the preceding review the principal constituents of quassia are quassiin, picrasmin, quassol, an alkaloid (?), a volatile oil (?), resin, mucilage, and pectin. The constitutions of the first three are not definitely known, and the actual presence of the volatile oil and alkaloid has not been definitely established.

2.—LITERATURE DEALING WITH QUASSIA EXTRACT AS AN INSECTICIDE

It is reported that quassia extract has been used as an insecticide in Europe for many years, but the earliest authentic record found by the writers occurs in 1885. On this date Ormerod (30) reports that the hop growers in England found quassia extract efficient upon the hop aphis. The proportion of ingredients used was generally 6 pounds of quassia chips and 3 pounds of soft soap to 100 gallons of water.

Alwood (1) prepared a decoction of quassia by using 1 pound of chips to 2 gallons of water. He says:

> Applied pure, it killed the lice (hop aphid) effectually where they were reached, but it will not spread. Only those under drops were killed. Diluted once it was still quite effective, but could not be used with any thoroughness. I do not consider this a practical remedy when used alone.

Smith (41, 42, 43) prepared a strong decoction of quassia and applied it externally and internally to rose chafers (*Macrodactylus subspinosus Fab.*). He claims that it was ineffective, regardless of how it was applied.

Riley and Howard (36, 37), basing their deduction upon the results of Alwood's experiments (1), report that quassia extract when used alone is greatly inferior to well-prepared kerosene emulsion for hop aphids.

Koebele (20) sprayed hop aphids on prune trees in the States of Oregon and Washington with a solution prepared in the proportion of 6 pounds of quassia chips and 3 pounds of soap to 100 gallons of water. He says:

> The numerous ants attending the Aphidids were not destroyed by this wash, and they carried off the lice not destroyed by the application the following day, leaving the immature lice dead upon the leaves. The action of the quassia is very slow and considerable time elapses before the lice are all destroyed.

Washburn (46) reports that a spray solution consisting of quassia extract and soap, barring the expense of the chips and the time consumed in the extraction, is recommended for the hop aphis in Oregon.

Gould (14) ascertained that a quassia extract solution not containing soap was inefficient for the San José scale on pear trees.

Fletcher (11, 12) reports that the decoction prepared in the proportion of 78 pounds of quassia chips and 7 pounds of whale-oil soap to 100 gallons of water is the standard remedy for the hop aphis in Ontario, and also that it has given most satisfactory results against other aphids with no injury to the foliage of the trees treated.

Howard (17), discussing the experiments of Celli and Casagrandi, who determined that the fumes from quassia wood kill aerial mosquitoes, summarizes the conclusions of the Italian authors as follows:

> It is, however, to be noted that for these odors, fumes, or gases to exercise their culicidal action they must fill or saturate the whole ambient; otherwise they produce only apparent death, or at most only a culicifugal action, which sometimes in houses may be useful in protecting man from being bitten by mosquitoes.

Piper (35) reports that a decoction prepared in the proportion of 28 pounds of quassia chips and 7 pounds of whale-oil soap to 100 gallons of water is used almost exclusively for the hop aphis. He says:

> It is quite as effective against other species of Aphis. The whale-oil soap without the quassia is of somewhat less efficiency.

Henderson (15) determined that a strong decoction of quassia without soap was ineffectual upon the apple aphis in Idaho, but when soap was added to it and the mixture was then diluted and applied warm the result was that nearly all of the aphids were killed.

Theobald (44), writing about the apple sucker (*Psylla mali* Schm.) in England, says:

> The only preventive we find of any use is spraying with quassia and soft soap as soon as the buds commence to swell and the larvæ are seen to be coming from the eggs. We usually use 6 or 8 pounds of soft soap and 8 pounds of boiled quassia chips to the 100 gallons of soft water.

Boucart (2, p. 376), compiling formulas and results obtained therefrom by several authors, cites six insecticides having a quassia basis. These are variously concocted, some being decoctions and others infusions, but each one contains soap, and, furthermore, one contains alcohol, one petroleum emulsion, and one carbolic acid. The originator of the one containing petroleum emulsion recommends it for destroying various caterpillars infesting fruit trees. The authors of the formulas containing only quassia extract, soap, and water say that these insecticides kill *Cochylis ambiguella* Hübn. (cochylis of the vine), the hop aphis, wheat aphis, green aphids, woolly aphis, peach aphis, gooseberry aphis, *Phytoptus ribis* W., and *Phytocoris militaris* Westw. (orchid bug).

Parker (32), in the laboratory sprayed branches of prune trees bearing prune aphids (*Hyaloptcrus pruni* Fab.) with a solution made by extracting

5.33 ounces of quassia chips with 2 quarts of water; 92 per cent of these aphids died. Other branches of prune trees were sprayed with a solution prepared in the proportion of 7 pounds of quassia chips to 250 gallons of water; 96 per cent of these aphids were killed. Parker ascertained that variously concocted formulas consisting of quassia extract and soap solution are effective upon the hop aphis (*Phorodon humuli* Schr.) in the field. He believes that the solution kills only by coming in contact with the insects. The same author (33, p. 6), in the laboratory and in the field sprayed hop aphids and prune aphids with three different formulas in the proportion of ingredients as follows: (1) 0.4 gm. of quassiin to 2,000 c. c. of water with whale-oil soap; (2) 0.4 gm. of quassiin to 2,000 c. c. of water with soap bark; and (3) 0.4 gm. of nicotine sulphate to 2,000 c. c. of water with soap bark. He concluded that the formulas containing quassiin were almost as effective as that containing nicotine sulphate. He did not test the effects of the quassiin solution upon other insects, but believes that it will prove effective elsewhere if used in proportions corresponding to the amounts of nicotine sulphate that are known to be effective.

METHODS OF PREPARATION AND EFFECTIVENESS OF QUASSIA EXTRACTS [1]

An investigation of the effectiveness of a substance as an insecticide may be divided, as a rule, into two distinct phases: (1) The preparation and preliminary testing in the laboratory of various extracts obtained from the substance; and (2) the testing under outside or field conditions of those solutions containing the extracts that have proved efficient in the laboratory.

I.—METHODS OF EXTRACTING QUASSIA CHIPS

The bitter principle, quassiin, which is considered to be the active constituent in quassia sprays, is claimed to be only slightly soluble in water. It is important, therefore, to know just what method of extraction is likely to insure the greatest quantity of this constituent. A review of the literature reveals a wide difference in the results obtained in extracting quassiin from the chips. The solubility of the quassiin, as found by various investigators, appears to vary greatly, and, owing to the confusion existing with respect to the practical methods of extracting this substance, it seems advisable to include in the present investigation some experiments to determine the value of the various methods.

(*a*) Quantities of Extract Removed by Successive Extraction

On the market, quassia chips vary greatly in size. A bag of this material is likely to contain pieces varying in size from several inches in length to very small fragments and sawdust. Since even the average-sized chips are quite large, it was thought probable that they could be

[1] The word "extract" throughout this paper means the solid material removed by a solvent.

extracted a number of times, and an effective extract obtained in each case. Consequently 10 gm. of medium-sized chips were extracted for 2 hours with 500 c. c. of distilled water. This mixture was then filtered and the filtrate evaporated to determine the quantity of extract obtained. The same chips were extracted successively six times by using the same amount of fresh distilled water each time, and the quantity of extract was determined after each extraction. The experiment was then repeated, the time of extraction in each case being 24, instead of 2 hours. The results are presented in Table I. In this and the other tables the quantity of extract does not necessarily mean the quantity of quassiin.

TABLE I.—*Quantity and percentage of extract dissolved by successive extractions of 10 gm. of quassia chips with 500 c. c. of distilled water for 2 and 24 hours, respectively*

Extraction No.	Quantity of extract obtained.				Extraction No.	Quantity of extract obtained.			
	Chips extracted 2 hours.		Chips extracted 24 hours.			Chips extracted 2 hours.		Chips extracted 24 hours.	
	Gm.	*Per cent.*	*Gm.*	*Per cent.*		*Gm.*	*Per cent.*	*Gm.*	*Per cent.*
1.....	0.1035	1.03	0.1535	1.53	4.....	0.015	0.15	0.0157	0.16
2.....	.0255	.25	.0275	.27	5.....	.0075	.075	.0145	.14
3.....	.0215	.21	.0197	.20	6.....	.0005	.005	.....	.....

It will be noted that after five extractions of two hours each, practically nothing further is extracted. The total extract in the five portions of 500 c. c. each is 0.1730 gm. When the chips were extracted for 24 hours, the total extract in the five portions of 500 c. c. each was 0.2309 gm., or 0.0579 gm. more than in the first case. It is evident from this that a relatively long period of soaking is essential in order to get the maximum quantity of quassiin in solution. It was observed that the extracts in all cases were bitter and the residues from the final extractions, although much fainter in taste, were still distinctly bitter. Figure 1 shows graphically the relative quantity of extract obtained in each case.

(*b*) Effect of Boiling the Chips

To determine the effect of boiling on the quantity of extract which may be dissolved from the chips, 10 gm. were boiled under a reflux condenser in 500 c. c. of distilled water for various periods of time. After cooling and filtering, the filtrate was evaporated and the quantity of extract was determined. Table II gives the results.

TABLE II.—*Quantity and percentage of extract obtained by boiling 10 gm. of quassia chips in 500 c. c. of distilled water for various periods*

Length of time chips were soaked.	Extract obtained.		Length of time chips were soaked.	Extract obtained.	
Hours.	*Gm.*	*Per cent.*	*Hours.*	*Gm.*	*Per cent.*
½.....	0.1467	1.46	8.....	0.2765	2.76
1.....	.1872	1.87	16.....	.2747	2.74
2.....	.195	1.95	24.....	.3327	3.32
4.....	.2435	2.43			

It would appear that boiling for one-half hour extracts as much material from the chips as cold maceration for 24 hours. These boiled extracts are all more highly colored than the cold macerated extracts, and it is to be expected that substances other than those found in the macerated extracts are dissolved from the wood under the influence of the higher temperature. Figure 2 illustrates graphically the results given in Table II. It will be observed that comparatively little extract is obtained after four hours' boiling; therefore it would hardly be economical to boil the chips longer than four or five hours.

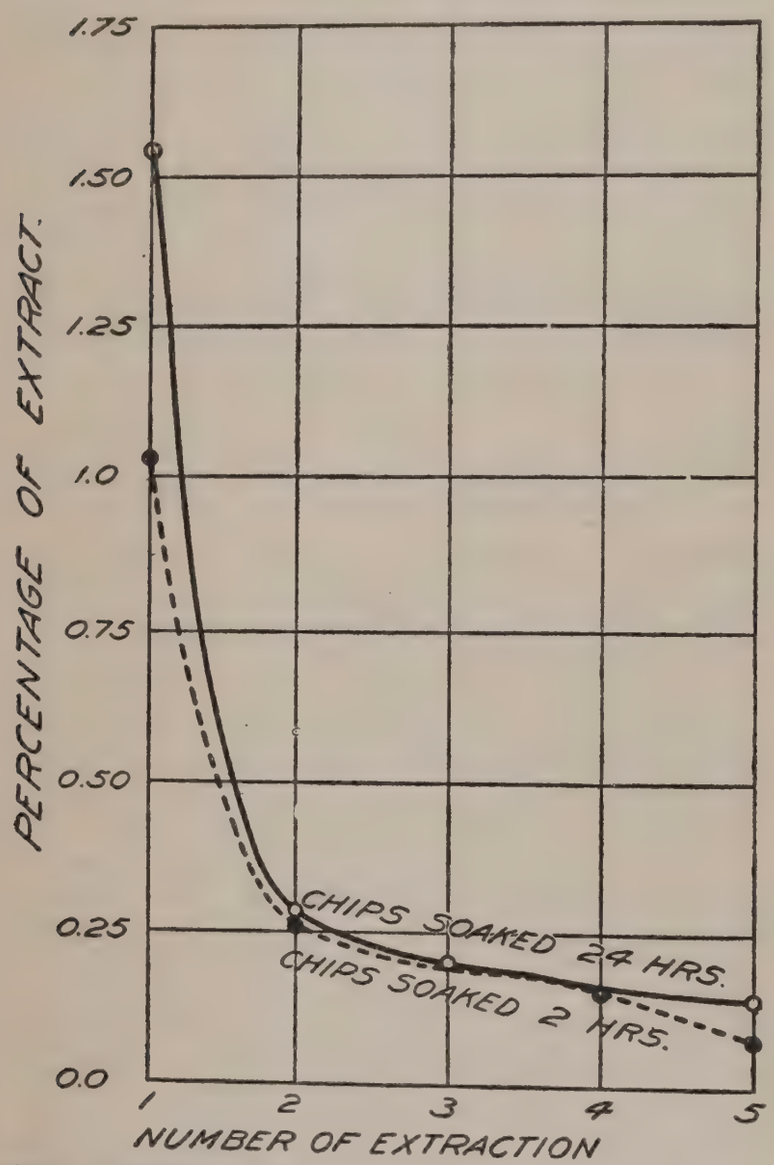

FIG. 1.—Graph showing the percentage of extract obtained by repeated soaking of 10 gm. of quassia chips with 500 c. c. of water for 2 and 24 hours, respectively.

(c) INFLUENCE OF SIZE OF CHIPS ON EXTRACTION

Whenever substances are extracted by maceration, the state of subdivision or comminution of the substance is of great importance. As a rule the finer the subdivision the more thorough is the action of the solvent. To determine whether the reduction of quassia wood to fine powder would materially increase the quantity of extract, a quantity of the wood was separated into a series of portions, varying in size from pieces 6 to 8 cm. long and 1 to 2 cm. wide, to a No. 200 powder [1] In each case 10 gm. of the wood were macerated for 24 hours in 500 c. c. of distilled water. After filtering the mixture and adding enough water to make 500 c. c., the entire quantity was evaporated and the quantity of extract was determined. A second extraction was made in each case. Table III is a tabulation of the results obtained.

[1] A No. 200 powder is one that will pass through a sieve having 200 meshes to the inch.

TABLE III.—*Influence of size of chips on the quantity of extract obtained by macerating 10 gm. of quassia chips in 500 c.c. of distilled water for 24 hours*

Chips.		Quantity of extract obtained.				
Sample No.	Size of chips.	First extraction.		Second extraction.		Total.
		Gm.	*P. ct.*	*Gm.*	*P. ct.*	*P. ct.*
1	6 to 8 cm. long and 1 to 2 cm. wide...	0.0655	0.65	0.0260	0.26	0.910
2	4 to 5 cm. long and 1 to 1½ cm. wide.	.0870	.87	.0280	.28	1.15
3	2 to 3 cm. long and ¾ to 1¼ cm. wide.	.1257	1.26	.0295	.29	1.55
4	15 to 25 mm. long and 5 to 10 mm. wide.....	.1147	1.15	.0217	.22	1.37
5	7 to 13 mm. long and 3 to 5 mm. wide.	.1395	1.39	.0252	.25	1.64
6	No. 5 powder.....	.1700	1.70	.0267	.26	1.96
7	No. 10 powder.....	.1580	1.58	.0365	.36	1.94
8	No. 20 to 40 powder.....	.1570	1.57	.0397	.40	1.97
9	No. 40 to 60 powder.....	.1930	1.93	.0455	.45	2.38
10	No. 60 to 100 powder.....	.2370	2.37	.0580	.58	2.95
11	No. 100 to 200 powder.....	.2625	2.62	.0775	.77	3.39
12	No. 200 powder and finer.....	.2930	2.83	.0910	.91	3.74

It will be noted that the quantity of extract dissolved by the water is proportional to the state of subdivision of the chips. This is especially true with regard to the first extraction. In figure 3, which shows graphically the relationship of the size of the chips to the quantity of extract obtained, it will be noted that relatively little extract is removed the second time. It is evident that a 24-hour maceration will extract from the chips such a percentage of the total water-soluble matter that a second extraction would be unprofitable. Reference to figure 1 will illustrate this further. It is noted that the second extraction removes only one-sixth as much material as the first.

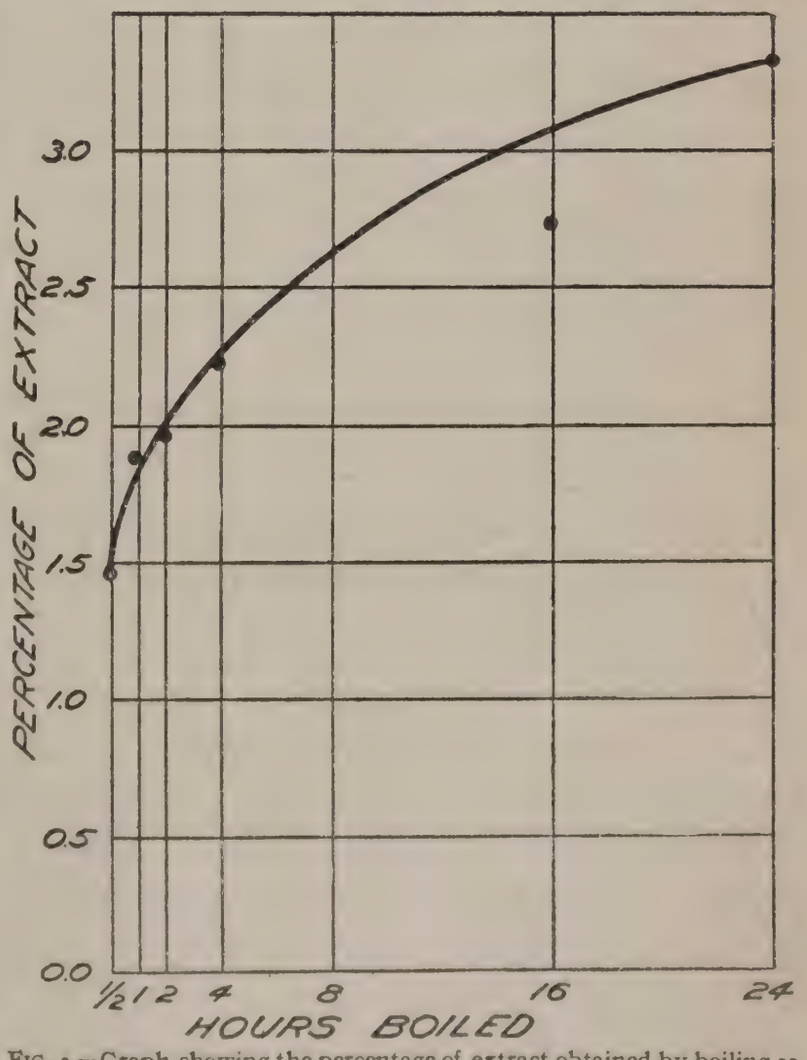

FIG. 2.—Graph showing the percentage of extract obtained by boiling 10 gm. of quassia chips with 500 c. c. of water for ½ 1, 2, 4, 8, 16, and 24 hours, respectively.

Quassia wood is difficult material to get into a fine state of comminution. The coarser subdivision can be obtained by shredding and the next smaller division can be effected by means of burr mills. The fine powders, however, can only be secured by continued action of a pebble mill or a chaser mill. The expense of reducing the wood to fine powder would therefore be too great to make its use in that form economical. When the cost of grinding is taken into consideration, it seems that the most economical form in which to use quassia wood is that corresponding to No. 5 to 7 in Table III. This material is about the size of coarse sawdust.

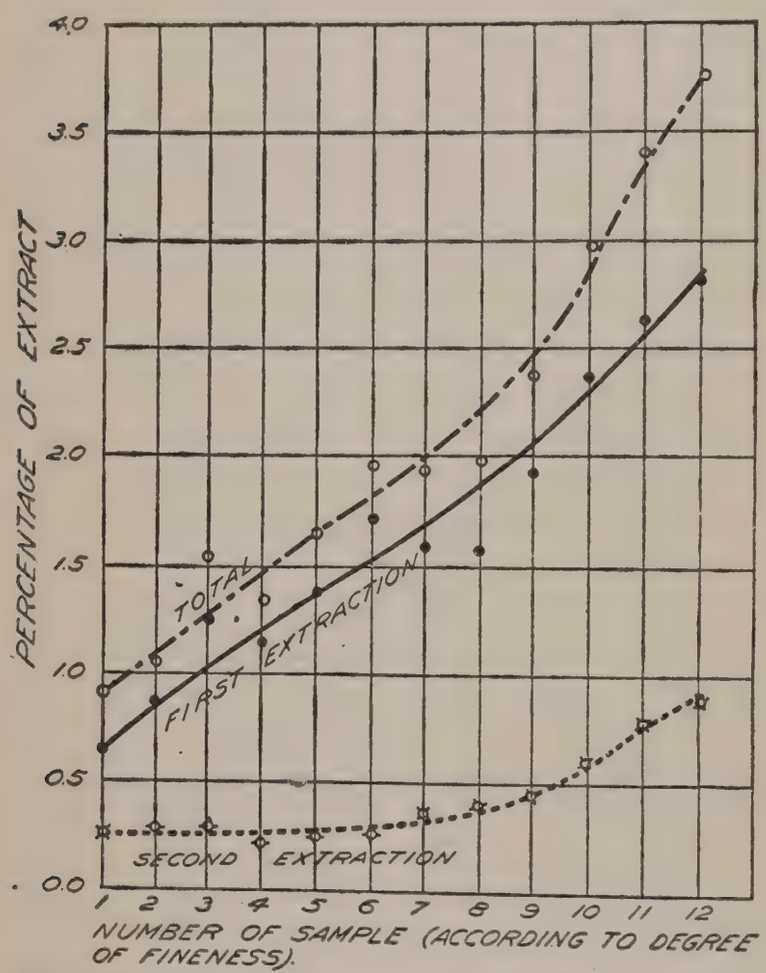

FIG. 3.—Graph showing the influence of the state of fineness of the quassia chips upon the percentage of extract obtained when extracting 10 gm. with 500 c.c. of water for 24 hours.

(*d*) Influence of Quantity of Water Used

In making spray solutions from quassia chips it is a question whether it is more expedient to soak the necessary quantity of chips in the entire quantity of water or to soak them in a small quantity of water and later dilute the filtrate to the quantity of solution wanted. The latter method is, as a rule, the more convenient one in large operations, because the chips can be soaked in a suitable barrel and later the dilution can be made in the spray tank. On the other hand, the first method, owing to the slight solubility of quassiin in water, would appear to insure the more thorough extraction. This method, however, involves the use of a soaking tank large enough to hold the entire volume of spray solution. In the following experiment an attempt was made to determine the effect of the volume of water used on the total quantity of extract dissolved from the chips.

Four portions of 10 gm. each of medium-sized chips were macerated for 24 hours, in 250, 1,000, 2,000, and 3,000 c.c. of distilled water, respectively. After filtering, 200 c.c. of each filtrate were evaporated,

and the amount of extract was determined. The results are embodied in Table IV.

TABLE IV.—*Effect of the quantity of water used on the total quantity of extract obtained from 10 gm. of quassia chips macerated 24 hours*

Experiment No.	Quantity of water used as solvent.	Quantity of extract in 200 c. c. of filtrate.	Total quantity of extract in spray solution if sufficient water were added to make 3,000 c. c.
	C. c.	*Gm.*	*Gm.*
1	250	0.1054	0.1317
2	1,000	.0286	.1430
3	2,000	.0155	.1550
4	3,000	.0116	.1740

It may be well to explain the above table with a practical example. If it were desired to make a 3,000-c. c. spray solution with 10 gm. of quassia chips, either of the two following methods might be used: (1) The chips should be soaked for 24 hours in a small quantity of water (for example, 250 c. c.) , and after filtering the mixture sufficient water added to make 3,000 c. c.; or (2) they should be soaked in the full quantity of water (3,000 c. c.) for 24 hours and the mixture then filtered. From the table it will be seen that in experiment 1, in which 250 c. c. of water were used as a solvent, 200 c. c. of filtrate yielded 0.1054 gm. of extract, while in experiment 4, in which 3,000 c. c. of water were used as a solvent, 200 c. c. of filtrate yielded only 0.0116 gm. of extract. However, upon diluting No. 1 with sufficient water to make 3,000 c. c., the total extract in the spray solution was 0.1317 gm., while the total extract in the 3,000 c. c. No. 4 is 0.1740 gm. It is seen, therefore, that by using the entire quantity of water to extract the chips, 32.1 per cent more extract is obtained than by extracting in a small quantity of water and subsequently diluting. While, of course, it is to be expected that a considerable percentage of the water-soluble extract is not quassiin, it may safely be assumed that extracting with the total quantity of water assures a greater percentage of quassiin in the spray solution.

2.—EXPERIMENTAL TESTS FOR SELECTION OF EFFECTIVE FORMULAS

In the preceding pages the quantitative determinations show the following: (1) Chips soaked for 2 hours in water yield during the first extraction four times as much extract as during the second extraction; but chips soaked for 24 hours yield during the first extraction six times as much extract as during the second extraction. (2) Chips boiled longer than four hours yield but little more extract than those boiled for this period, and the quantity obtained is about one and one-half times that

obtained when chips are soaked for 24 hours. (3) The smaller the chips and the finer the powder, the greater is the quantity of extract removed. And (4) the larger the volume of water used as a solvent, the greater is the quantity of extract removed—that is, 10 gm. of chips soaked for 24 hours in 3,000 c. c. of water yielded 32.1 per cent more extract than 10 gm. soaked for the same period in 250 c. c. of water.

It now remains to be determined whether or not experimental results obtained by using quassia extracts on insects will support the preceding data. Preliminary experiments soon proved that quassia extracts are efficient on aphids only; therefore the results dealing with the effectiveness of these extracts on other insects are briefly discussed under the heading, "Pharmacological effects of quassiin."

In the various experiments in which many experimental formulas containing quassia extracts were used for the purpose of eliminating all those formulas found to be inefficient in the laboratory, the following aphids were employed: Tulip-tree aphids (*Macrosiphum liriodendri* Mon.), rose aphids (*Macrosiphum rosae* L.), nasturtium aphids (*Aphis rumicis* L.), cabbage aphids (*Aphis brassicae* L.) on kale, pea aphids (*Macrosiphum pisi* L.), aphids (*Aphis* sp.) on bladder senna (*Colutea arborescens* L.), woolly beech aphids (*Phyllaphis fagi* L.), and those aphids (*Chaitophorus populicola* Thos.) found on Carolina poplars. The following leaves, branches, and entire plants, each bearing many aphids, were collected between 7 and 8 a. m. and were placed in bottles of water on a long table by windows: Leaves of tulip trees (*Liriodendron tulipifera*), nasturtiums (*Tropaeolum* spp.), and kale (*Brassica oleracea viridis*); branches of rose-bushes (*Rosea* spp.), bladder senna, beech trees (*Fagus americana*), and Carolina poplars (*Populus deltoides*); and entire sweet-pea plants (*Lathyrus odoratus*) in small pots. The aphids were then sprayed with an atomizer, and the bottles and pots, with their contents, were so arranged on the table that each of them received an equal share of light. The insects were counted before any of them died, and at regular intervals throughout the day those remaining alive were recorded. The three following interfering factors were usually present: (1) To a limited degree the aphids left the leaves and branches and crawled toward the windows; (2) most of the spray solutions were slightly repellent and certainly the less effective ones caused a small percentage of the aphids to migrate from the leaves and branches; (3) the tulip-tree leaves late in the afternoon showed evidence of drying, which consequently caused the remaining live insects to leave them sooner or later. The first factor is insignificant when comparing various results obtained in the laboratory; but, when these results are compared with those obtained outside the laboratory, it must be taken into account. Inside and outside the laboratory the second factor probably has the same weight; but, when the mortality of aphids sprayed is compared with that of those not sprayed, a small probable error should usually be allowed. To overcome most of the error caused by the third

factor, all of the results recorded later than 9 hours after applying the spray solutions were eliminated.

Since the extract of quassia wood (see p. 510) contains constituents other than the supposedly active one called "quassiin," it was considered expedient to begin the experimentation with quassiin in as pure a form as could be obtained on the market. Various solvents were used not only on a small quantity of commercial quassiin powder labeled "purified powder" but also on quassia chips and quassia powder.

(*a*) Experiments with Quassiin Powder

Before a discussion of the results obtained by using the extracts dissolved from the quassiin powder it was first thought advisable to determine the solubility of this particular powder in different solvents. According to Schmidt (39), quassiin is difficultly soluble in water or ether, but is readily soluble in alcohol, chloroform, or acetic acid. It is also dissolved by caustic alkalies and concentrated acids, but not by alkaline carbonates.

To determine the solubility of the above-mentioned quassiin in (1) distilled water, (2) in a 0.05 per cent sodium-carbonate solution, (3) in a 0.05 per cent lye solution, and (4) in a soap solution (1.8 gm. of potash-fishoil soap to 1,000 c. c. of water, or 1.6 pounds of soap to 100 gallons of water), the following method was used: An excess of the quassiin powder was placed in a flat 1,000 c. c. bottle containing 500 c. c. of distilled water, and then the bottle with its contents was shaken by means of a mechanical device for 5 hours; this process was repeated three times by using the three other enumerated solvents, one at a time. After filtering the mixture, 100 c. c. of each filtrate obtained were evaporated in a tared dish, and the quantity of the solids remaining in the dish was determined. These solids represented the extract from the quassiin powder plus the solid matter contained in each solvent. It was therefore necessary to determine the quantity of solid matter in 100 c. c. of each solvent not containing quassiin extract, in order to ascertain the weight of the extract from the quassiin powder. The results obtained are summarized in Table V.

Table V.—*Solubility of quassiin powder in various solvents*

Solvent.	Solid matter in—		Quantity of extract in 100 c. c. of filtrate.	Solubility of quassiin powder in solvent.
	100 c. c. of filtrate.	100 c. c. of solvent.		
	Gm.	*Gm.*	*Gm.*	*Parts.*
Distilled water	0.0322	0.0001	0.0321	1 to 3,084
0.05 per cent sodium carbonate solution	.1592	.0501	.1091	1 to 917
Soap solution (1.8 gm. to 1,000 c. c.)	.2735	.1528	.1207	1 to 828
0.05 per cent lye solution	.2325	.0501	.1824	1 to 548

According to Table V the addition of an alkali to the water greatly increases the solubility of the quassiin powder—for example, the addition of the lye increased the solubility from five to six times, while the addition of the soap increased it almost four times. It now remains to be determined which one of the four solvents used in dissolving the quassiin powder is preferable in the preparation of spray solutions.

(1) ETHER AND WATER AS SOLVENTS

Owing to the possibility that this quassiin powder may be impure, the procedure detailed below was employed to test its purity. Schmidt (39) says that quassiin is difficultly soluble in ether or water. Merck (24) succeeded in separating a tasteless and supposedly inert substance, which he called "quassol," from impure quassiin powder by using ether.

EXPERIMENT 1.—In an attempt to purify this supposedly impure quassiin powder, 5 gm. of it were extracted with 500 c. c. of ordinary ether for 24 hours, during 6 of which the material was constantly shaken. After filtering, the amount of extract contained in 100 c. c. of the filtrate was determined, and it was found that 1.8 gm., or 35 per cent, of the quassiin powder went into solution in the ether. The ether-soluble residue resulting was of a resinous character and not as bitter as the quassiin powder. Since quassiin is somewhat soluble in ether, it would seem that this residue contained both quassol and quassiin, but probably a greater percentage of the former, because it was not so bitter as the quassiin powder. A small portion (0.57 gm.) of the resinous material was extracted with 500 c. c. of water for 24 hours, during 8 of which the mixture was constantly agitated. After filtering, the filtrate was sprayed upon nasturtium aphids, 58 per cent of which afterwards died (see Table VI). Since this liquid was not very bitter and as it killed only about one-half of the aphids tested, it may be inferred that the extract contained in it was mostly quassol. Since ordinary ether contains a trace of water, it was thought advisable to repeat this experiment by using anhydrous ether for exhausting the quassiin powder. This ether extracted 45 per cent of the powder. A water extract of the ether-soluble portion killed 50 per cent of the nasturtium aphids and 54 per cent of the pea aphids.

EXPERIMENT 2.—In this experiment an extract was prepared from the portion of the quassiin powder not dissolved by the ordinary ether, described in experiment 1, by extracting an excess of it with water for 24 hours, during 8 of which it was constantly shaken. After filtering the mixture, the filtrate, which was much more bitter than that used in the preceding experiment, was sprayed upon nasturtium aphids, all of which afterwards died. An extract was also prepared from the portion of the powder not dissolved by the anhydrous ether, described in the preceding experiment; this killed 95 per cent of the nasturtium aphids and 82 per cent of the pea aphids. Since these residues did not contain quassol, it may be regarded that the extracts used were practically pure quassiin.

(2) WATER AS A SOLVENT

EXPERIMENT 3.—One-tenth gm. of quassiin powder was macerated in 500 c.c. of water for 2 hours with frequent agitation and the mixture was then filtered. Only the undiluted filtrate and one dilution (1 : 5) of it killed practically all of the aphids tested (see Table VI).

EXPERIMENTS 4 TO 12.—The procedure of these was similar to the one just above, and the results obtained are tabulated in Table VI.

TABLE VI.—*Methods of preparing spray solutions from quassiin powder with various solvents and results of preliminary tests of these solutions on aphids in laboratory*

Experiment No.	Procedure.	Ether solvents, dilutions, and time of extractions.	Species of aphids.	Number of aphids used.	Results.	
					Percentage killed.	Minimum time required to kill percentage indicated.
						Hours.
1	Excess of powder shaken in ether, evaporated, and residue extracted with water.	(*a*) Ordinary ether	*Aphis rumicis*.....	79	58	8
		(*b*) Anhydrous ether.	.....do.....	104	50	7
		(*c*) Anhydrous ether.	*Macrosiphum pisi*.	62	54	7
2	Powder exhausted with ether and undissolved portions then extracted with water.	(*a*) Ordinary ether	*Aphis rumicis*.....	105	100	8
		(*b*) Anhydrous ether.	.....do.....	129	95	7
		(*c*) Anhydrous ether.	*Macrosiphum pisi*.	39	82	7
3	0.1 gm. extracted with 500 c. c. of water for 2 hours and diluted with water.	(*a*) No dilution....	*Macrosiphum liriodendri*.	29	100	4
		(*b*) No dilution....	.....do.....	508	90	8
		(*c*) No dilution....	*Chaitophorus populicola*.	335	100	8
		(*d*) Dilution 1:5...	*Macrosiphum liriodendri*.	39	100	9
4	0.1 gm. extracted with 1,000 c. c. of water for following periods:	(*a*) 1 hour.....	.....do.....	16	100	6
		(*b*) 3 hours.....	.....do.....	59	100	5
		(*c*) 5 hours.....	.....do.....	39	100	7
		(*d*) 24 hours.....	.....do.....	16	100	5
5	0.1 gm. boiled in 1,000 c. c. of water for 2 hours and diluted with water.	(*a*) No dilution....	.....do.....	36	100	2½
		(*b*) Dilution 1:5...	.....do.....	31	100	3
		(*c*) No dilution....	.....do.....	114	33	8
6	An excess of powder shaken in distilled water for 5 hours.	.....	*Aphis* sp.....	277	82	8
				300	95	8
7	0.1 gm. extracted with 1,000 c. c. of soap solution for following periods:	(*a*) 1 hour.....	*Macrosiphum liriodendri*.	46	100	3
		(*b*) 3 hours.....	.....do.....	47	100	2½
		(*c*) 5 hours.....	.....do.....	46	100	4
		(*d*) 24 hours.....	.....do.....	21	100	4
8	0.1 gm. boiled in 1,000 c. c. of soap solution for 2 hours and diluted with soap solution.	(*a*) No dilution....	.....do.....	294	100	2
		(*b*) Dilution 1:5...	.....do.....	111	100	2
		(*c*) Dilution 1:10..	.....do.....	61	100	2
		(*d*) Dilution 1:50..	.....do.....	29	100	2
		(*e*) Dilution 1:100.	.....do.....	30	100	2½
9	0.1 gm. extracted with 1,000 c. c. of 1 per cent sodium-carbonate solution for following periods:	(*a*) 1 hour.....	.....do.....	31	100	4
		(*b*) 3 hours.....	.....do.....	40	100	4
		(*c*) 5 hours.....	.....do.....	37	100	5
		(*d*) 24 hours.....	.....do.....	22	100	5
10	0.1 gm. boiled in 1,000 c. c. of 1 per cent sodium-carbonate solution for 2 hours and diluted with water.	(*a*) No dilution....	.....do.....	70	100	2½
		(*b*) Dilution 1:5...	.....do.....	29	100	6
11	0.1 gm. extracted with 1,000 c. c. of 1 per cent lye solution for following periods:	(*a*) 1 hour.....	.....do.....	54	100	3
		(*b*) 3 hours.....	.....do.....	128	100	3
		(*c*) 5 hours.....	.....do.....	101	100	3
12	0.1 gm. boiled in 1,000 c. c. of 1 per cent lye solution for 2 hours and diluted with water.	(*a*) No dilution....	.....do.....	29	100	9

Reference to Table VI shows the following: The ether-water extract (probably mostly quassol) of impure quassiin powder killed about one-half of the aphids tested (experiment 1), while the practically pure quassiin killed 92 per cent of those sprayed (experiment 2). Generally speaking, all of the remaining extracts were efficient within a few hours. In all but one case it is indicated that boiling slightly increases the efficiency of the extracts. Had they been boiled longer than two hours, this indication might have been reversed. Boiling quassiin powder

with lye solution seems to destroy the insecticidal value of the extract obtained, lye probably causing decomposition of the quassiin. There seems to be no difference in effectiveness between the unboiled soap-solution and the lye-solution extracts; but the soap-solution extract obtained by boiling the powder for two hours appears to be the most effective of the extracts obtained from this powder. It is thus seen that the addition of lye and soap to the water materially increases the effectiveness of the extracts obtained, while the addition of sodium carbonate to the water only slightly increases the effectiveness of the extract obtained. These results agree with those of the quantitative determinations recorded in Table V, with the exception that the effectiveness of the extract obtained by the sodium-carbonate solution does not correspond to the quantity of extract removed by this solvent.

(*b*) Experiments with Quassia Chips

According to the results of the quantitative determinations (Table III), it was found that the greater the comminution of the quassia material the larger is the quantity of extract capable of being removed. Hence, extracts obtained from quassia powder should be more efficient than those from quassia chips. In the preliminary experiments with aphids, it was ascertained that the former extracts were little, if any, more efficient than the latter extracts. This may be due to two reasons: (1) Since these experiments were performed with such a small number of aphids, the difference in efficiency was not noticeable; and (2) the powder and chips were not from the same identical tree, and probably not from trees of the same species. Since quassia powder will in all probability never be used to any great extent in practical spraying, owing to the expense involved in pulverizing the chips, it will be omitted from the following discussions, and only those results pertaining to the extracts from quassia chips will be briefly described. In all of the following experiments only tulip-tree aphids were used, and for the sake of brevity only the first experiment is briefly stated, and all of them are then summarized in Table VII.

(1) water as a solvent

Experiment 13.—Twenty-five gm. of chips were macerated in 350 c. c. of water for one-half hour; this process was repeated four times in 1, 3, 10, and 48 hour periods. With the extracts thus obtained the length of time required to kill the aphids tested varied from four to eight hours (see Table VII).

Reference to Table VII shows that the summary of the results of these experiments agrees closely with that of the results of the experiments recorded in Table VI, which deals with quassiin. Briefly stated, the similarity of these two summaries is as follows: The addition of lye and soap to the water greatly increases the effectiveness of the extracts obtained, while the effectiveness of the extract dissolved by the sodium-carbonate solution is only slightly better than that of the water extract.

TABLE VII.—*Methods of preparing spray solutions from quassia chips with various solvents and results of preliminary tests of these solutions on tulip-tree aphids (Macrosiphum liriodendri Mon.) in laboratory*

Experiment No.	Object of methods.	Procedure.	Length of time of extractions, dilutions, number of extractions, and strength of solvents.	Number of aphids used.	Length of time required to kill aphids.
					Hours.
13	Effect of length of time of maceration of chips.	25 gm. of chips macerated in 350 c. c. of water for:	(*a*) ½ hour	283	8
			(*b*) 1 hour	92	7
			(*c*) 3 hours	164	7
			(*d*) 10 hours	128	7
			(*e*) 48 hours	32	4
14	Effect of dilution of water containing extract of chips.	25 gm. of chips macerated in 350 c. c. of water for 24 hours and diluted with water.	(*a*) Dilution 1 : ¼	143	7
			(*b*) Dilution 1 : ½	89	9
			(*c*) Dilution 1 : 1	67	9
15	Effect of repeated maceration of chips.	25 gm. of chips extracted with 350 c. c. of water for 2 hours; filtered and extraction repeated.	(*a*) First extraction	34	6
			(*b*) Secondextraction.	37	7
16	Effect of boiling and length of time of boiling chips.	25 gm. of chips boiled in 350 c. c. of water; evaporated water replaced.	(*a*) Boiled ½ hour	223	4
			(*b*) Boiled 1 hour	294	4
			(*c*) Boiled 2 hours	77	4
			(*d*) Boiled 5 hours	173	4
17	Effect of diluting boiled water containing extract of chips.	25 gm. of chips boiled in 350 c. c. of water for 2 hours under reflux condenser and then diluted with water.	(*a*) Dilution 1 : ¼	131	4
			(*b*) Dilution 1 : 1	86	4
			(*c*) Dilution 1 : 2	142	4
			(*d*) Dilution 1 : 4	161	6
18	Effect of repeated boiling of chips.	25 gm. of chips boiled in 350 c. c. of water for 2 hours; filtered and process repeated.	(*a*) First extraction	339	4
			(*b*) Second extraction.	220	4
19	Effect of maceration of chips in soap solution and subsequent boiling.	25 gm. of chips macerated for 24 hours in 350 c. c. of soap solution and boiled for 2 hours.	.....	48	4
20	Effect of diluting soap solution containing extract of chips with water.	25 gm. of chips macerated in 350 c. c. of soap solution for 24 hours and diluted with water.	(*a*) No dilution	101	2
			(*b*) Dilution 1 : 2	43	3
			(*c*) Dilution 1 : 5	72	5
			(*d*) Dilution 1 : 25	36	6
21	Effect of diluting soap solution containing extract of chips with soap solution.	25 gm. of chips macerated in 350 c. c. of soap solution for 24 hours and diluted with soap solution.	(*a*) Dilution 1 : 2	23	2
			(*b*) Dilution 1 : 5	18	3
			(*c*) Dilution 1 : 10	14	3
			(*d*) Dilution 1 : 25	76	5
22	Effect of macerating chips in 1 per cent sodium-carbonate solution with subsequent boiling.	25 gm. of chips macerated in 350 c. c. 1 per cent sodium-carbonate solution for 24 hours and then boiled for 2 hours.	.....	31	5
23	Effect of macerating chips in sodium - carbonate solutions.	25 gm. of chips macerated for 24 hours in 350 c. c. of sodium-carbonate solution of the following strength:	(*a*) 1.0 per cent	102	4
			(*b*) 0.5 per cent	23	5
			(*c*) 0.3 per cent	64	6
			(*d*) 0.1 per cent	15	5
			(*e*) 0.05 per cent	22	5
24	Effect of macerating chips in sodium - carbonate solution and then diluting with water.	25 gm. of chips macerated in 350 c. c. of 0.05 per cent sodium-carbonate solution for 24 hours and diluted with water.	(*a*) No dilution	56	5
			(*b*) Dilution 1 : 5	53	6
			(*c*) Dilution 1 : 25	43	9
25	Effect of macerating chips in lye solutions.	25 gm. of chips macerated for 24 hours in 350 c. c. lye solution of following strength:	(*a*) 0.5 per cent	24	2
			(*b*) 0.3 per cent	28	2
			(*c*) 0.1 per cent	17	2
			(*d*) 0.05 per cent	34	2
26	Effect of macerating chips in lye solution and then diluting with water.	25 gm. of chips macerated in 350 c. c. of 0.05 per cent lye solution for 24 hours and diluted with water.	(*a*) No dilution	81	2
			(*b*) Dilution 1 : 5	93	6
			(*c*) Dilution 1 . 25	33	8

With the exception of the effectiveness of the extract removed by the sodium-carbonate solution, these results agree with those of the quantitative determinations recorded in Table V. Furthermore, all of these results closely agree with the statement made by Schmidt (39), who

claims that quassiin is slightly soluble in water, and is readily soluble in the caustic alkalies, but is not soluble in the alkali carbonates. Table VII further shows that extracts from chips boiled for 5 hours are slightly more effective than those from chips soaked for 24 hours, results agreeing with those of the quantitative determinations. But the effectiveness of the first extract from chips soaked for 2 hours is only slightly better than that of the second extract, whereas the ratio should be 4 to 1, in order to agree with the quantitative determinations; however, experiments performed in the laboratory on a large scale (p. 515) with the first and second extracts give a ratio of about 5 to 2. The most important result recorded in Table VII is that the soap-solution extract and lye-solution extract are equally effective, but, when the solutions containing the extracts are diluted, the former with soap solution and the latter with water, it is readily seen that the dilutions containing the soap-solution extract are much more effective and more economical, because they already contain the necessary "spreader," while the lye dilutions to be equally effective must have soap added to them before they are applied.

3.—EFFECTIVENESS OF SOME ECONOMIC FORMULAS

The preceding preliminary experiments clearly show that extracts from quassia chips soaked in water are less effective than those from chips boiled in water; but, on the other hand, extracts from chips soaked in soap solution, sodium-carbonate solution, and lye solution are more effective than those from chips boiled in these three solvents. This seems to indicate that at a high temperature alkalies decompose quassiin. As already stated, soap-solution and lye-solution extracts, not boiled, are the most effective ones found; and of these two extracts the former is the more economical and perhaps the more efficient for practical work. The soap-solution extract was further tested in the laboratory before it was applied in practical work, but the lye-solution extract did not seem to warrant further tests.

The following experiments were therefore performed with variously concocted formulas containing soap-solution extract to determine whether or not quassia extract may be employed as a general insecticide for all aphids. In each formula the soap was used in the proportion of 1.6 pounds to 100 gallons of water. This amount of soap has no detrimental effect upon the plants sprayed and very little upon the aphids.

To be able to compare more accurately the effectiveness of the various formulas, experiments were first performed in the laboratory on a small scale, and then outside the laboratory on a larger scale; with this method the live insects in the laboratory were counted at regular intervals, but outside the laboratory they were generally estimated. In order to have a standard by which the efficiency of quassia extract might be judged, nicotine sulphate in soap solution and also in water was sprayed upon aphids.

(*a*) Effectiveness of Spray Solutions Applied in Laboratory

The aphids were collected and were sprayed as described on page 508. The number used for each individual test varied from 124 to 436, with 253 as an average. Reference to Table VIII shows the following: Of the four species sprayed, the mortality of *Macrosiphum liriodendri* was the lowest and that of *Aphis* sp. the highest; the "wool" on *Phyllaphis fagi* seemed to prevent the spray solution from thoroughly wetting these aphids. From the laboratory viewpoint formulas 1A and 3A (first extracts) were efficient, but only upon two of the four species sprayed. For each of the four formulas the solution containing the second extract was less effective than that containing the first extract, indicating that more of the toxic principle was removed from the chips during the first than the second extraction. Formula 3A (first extract), the one used by Parker (32) on the hop aphis, was efficient upon only *Aphis* sp. and *Chaitophorus populicola* in the laboratory, but it is shown on page 517 that this formula is not efficient upon the same species of Aphis outside the laboratory and probably not upon *C. populicola*, although the latter species was not sprayed outside the laboratory.

Table VIII.—*Effectiveness of quassia extracts, soap solution, and nicotine sulphate applied in the laboratory*

Formula No. and extract No.	Quantity of quassia chips used.	Quantity of fish-oil-soap solution (1.6 pounds of soap to 100 gallons of water) used as solvent.	Length of time chips soaked.	Stock solution.	Final dilution with fish-oil-soap solution.	Quantity of chips used to 100 gallons of water.	Percentage of aphids dead 9 hours after application of spray solutions.			
							Macrosiphum liriodendri on tulip-tree leaves.	*Aphis* sp. on bladder senna branch.	*Phyllaphis fagi* on beech-tree leaves.	*Chaitophorus populicola* on Carolina poplar branches.
	Gm.	*C. c.*	*Hours.*	*C. c.*	*Parts.*	*Pounds.*				
1A (first extract)..	25.0	350	24	350	1 : 50	1.26	74	100	76	98
1B (second extract).....	25.0	350	24	350	1 : 50	1.26	56	.....	.....	.....
2A (first extract)..	25.0	350	24	350	1 : 35	1.81	81	.....	.....	.....
2B (second extract).....	25.0	350	24	350	1 : 35	1.81	48	.....	.....	.....
3A (first extract)..	6.3	[a] 2,000	24	2,000	None.	2.80	90	100	86	99
3B (second extract).....	6.3	2,000	24	2,000	...do...	2.80	76	.....	.....	.....
4A (first extract)..	25.0	350	24	350	1 : 20	3.16	92	.....	.....	.....
4B (second extract).....	25.0	350	24	350	1 : 20	3.16	77	.....	.....	.....
Fish-oil-soap solution (control)....	.....	.....	.....	.....	.....	.....	1	5	3	3
Nicotine sulphate (1 : 1,200 of soap solution).....	.....	.....	.....	.....	.....	.....	95	.....	.....	.....
Nicotine sulphate (1 : 1,200 of water).....	.....	.....	.....	.....	.....	.....	60	.....	.....	100

[a] In this formula the chips were soaked for 24 hours in 2,000 c. c. of water, and the soap was added subsequently.

(*b*) Effectiveness of Spray Solutions Applied Outside the Laboratory

In the experiments described under this heading various plants, all badly infested with aphids, were sprayed early in the morning with a hand sprayer, and the following morning the number of aphids killed was estimated. Reference to Table IX shows the following: Formula 3A, the one used by Parker (32) on the hop aphis, was efficient upon only *Aphis rumicis*, but killed 95 per cent of the aphids on the ragweed and asters. Formula 6B (first extract) was efficient upon the aphids on the ragweed and asters, but killed only 95 per cent of the pea aphids, *Aphis* sp., and rose aphids tested; the second extract of the same chips was not efficient upon any of these aphids. Formula 7 was efficient upon all the aphids tested, but the quantity of chips employed is so great that the formula could not be used economically for practical spraying. Not one of those formulas, even including nicotine sulphate (1:1,200 of soap solution) was efficient upon *Myzus persicae* on the eggplant.

(*c*) Comparative Rapidity of Action of Quassia Extract and Nicotine Sulphate

Since formula 6B (first extract, Table IX) is somewhat less expensive (excluding the labor of preparing it) than nicotine sulphate (1:800 of soap solution), and, as its efficiency 24 hours after its application is comparable to that of the nicotine-sulphate solution, the following experiments were performed in the laboratory to determine the rapidity of the action of these two insecticides, so that the effects of a shower upon aphids sprayed with these two solutions might be deduced. In each individual experiment the aphids were first sprayed with one or the other insecticide and then with tap water after one of the intervals of 5, 10, 20, 30, 60, or 120 minutes. The following plants and aphids were used: Kale leaves bearing 180 to 425 aphids; rose branches bearing 22 to 115 aphids; nasturtium leaves bearing 89 to 107 aphids; and bladder-senna branches bearing 36 to 92 aphids.

Twenty-four hours after applying formula 6B, the following aphids were dead: None of those sprayed with tap water after 5, 10, and 20 minute intervals; a few nasturtium aphids sprayed with tap water after a 30-minute interval; a few of those on the kale leaf and bladder-senna branch and about one-half of those on the nasturtium leaf sprayed with tap water after a 60-minute interval; most of those on the kale leaf and bladder-senna branch, practically all on the nasturtium leaf, but only a few of the rose aphids sprayed with tap water after an interval of 120 minutes. All the aphids on a kale leaf sprayed with this formula, but not later with tap water, were dead 6 hours after being sprayed; all of those on another leaf sprayed with the nicotine-sulphate solution, but not later with tap water, were dead 2 hours after being sprayed.

TABLE IX.—*Effectiveness of quassia extracts, soap solution, and nicotine sulphate applied outside the laboratory*

Formula No. and extract No.	Quantity of quassia chips used.	Quantity of fishoil-soap solution (1.6 pounds of soap to 100 gallons of water) used as solvent.	Length of time chips soaked.	Stock solution.	Final dilution with fishoil-soap solution.	Quantity of chips used to 100 gallons of water.	Approximate number of aphids sprayed and percentage of aphids dead 24 hours after application of spray solutions.											
							Aphis rumicis on dwarf nasturtiums.		*Macrosiphum ambrosiae* on giant ragweed.		*Macrosiphum* sp. on aster plants.		*Macrosiphum pisi* on sweet peas.		*Aphis* sp. on bladder senna.		*Macrosiphum rosae* on rosebushes.		*Myzus persicae* on eggplant in greenhouse.	
							Number sprayed.	Percentage killed.	Number sprayed.	Percentage killed.	Number sprayed.	Percentage killed.	Number sprayed.	Percentage killed.	Number sprayed.	Percentage killed.	Number sprayed.	Percentage killed.	Number sprayed.	Percentage killed.
	Gm.	*C. c.*	*Hours.*	*C. c.*	*Parts.*	*Lbs.*												
1A (first extract)	25.0	350	24	350	1 : 50	1.26	Thousands.	25	Hundreds.	70	.....	.....	.....	.....	160	25	780	20	Hundreds.	25
2A (first extract)	25.0	350	24	350	1 : 35	1.81	.....	.....	.....	.....	.....	.....	.....	.....	160	50	.....	.....	.....	.....
3A (first extract)	6.3	[a]2,000	24	2,000	None.	2.80	Thousands.	99	Hundreds.	95	300	95	320	90	160	75	180	40	Hundreds.	25
4A (first extract)	25.0	350	24	350	1 : 20	3.16	.....	.....	.....	.....	.....	.....	.....	.....	160	90	2,700	50	.....	.....
5 (first extract)	25.0	350	24	2,000	None.	11.00	.....	.....	.....	.....	.....	.....	.....	.....	1,340	80	1,540	80	.....	.....
6A (first extract)	50.0	350	24	2,000	None.	22.00	.....	.....	.....	.....	.....	.....	.....	.....	1,120	90	1,500	90	.....	.....
6B (first extract)	50.0	2,000	24	2,000	None.	22.00	.....	.....	Hundreds.	99	300	100	320	95	1,120	95	1,500	95	Hundreds.	25
6B (second extract)	50.0	2,000	24	2,000	None.	22.00	.....	.....	...do.....	90	300	40	.....	.....	1,120	70	1,500	90	.....	.....
6C (first extract)	50.0	350	6	2,000	None.	22.00	.....	.....	.....	.....	.....	.....	.....	.....	1,120	90	1,500	90	.....	.....
6D (first extract)	50.0	2,000	6	2,000	None.	22.00	.....	.....	.....	.....	.....	.....	.....	.....	1,120	95	1,500	94	.....	.....
7 (first extract)	25.0	350	24	350	None.	63.30	Thousands.	100	.....	.....	300	100	.....	.....	.....	.....	180	100	.....	.....
Fishoil-soap solution (control).	.....	.....	.....	.....	.....	.....	...do.....	5	.....	.....	.....	.....	.....	.....	160	5	.....	.....	Hundreds.	0
Nicotine sulphate (1 : 1,200 of soap solution).	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	160	95	.....	.....	...do.....	35
Nicotine sulphate (1 : 800 of soap solution).	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	1,900	98	1,350	95	.....	.....
Nicotine sulphate (1 : 1,200 of water).	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	1,120	60	.....	.....	.....	.....

[a] In this formula the chips were soaked for 24 hours in 2,000 c. c. of water, and the soap was subsequently added.

Twenty-four hours after applying the nicotine-sulphate solution the following aphids were dead: None of those sprayed with tap water after 5 and 10 minute intervals; a few of those on the kale and nasturtium leaves sprayed with tap water after a 20-minute interval; several of those on the kale leaf and nearly all on the nasturtium leaf sprayed with tap water after a 30-minute interval; nearly all belonging to the four species sprayed with tap water after a 60-minute interval; and all belonging to the four species sprayed with tap water after a 120-minute interval.

The foregoing results show that nicotine sulphate acts very quickly, while quassia extract acts very slowly. These results also indicate that a shower 2 hours after the application of these insecticides does not affect the efficiency of the nicotine sulphate, while it greatly reduces the efficiency of quassia extract.

PHARMACOLOGICAL EFFECTS OF QUASSIIN

The preceding experiments show that quassia extract kills aphids only by coming in contact with them, but it still remains to be shown how it kills them. This phase of the work involves a careful study of the physiological effects of quassiin on aphids and of what tissue is vitally affected.

I.—PHYSIOLOGICAL EFFECTS OF QUASSIIN

To determine how quassiin in the form of powder and in spray solutions affects insects when dusted or sprayed upon them, the physiological effects of this substance on the insects were observed. Of the various insects used in the experiments it was ascertained that quassiin is fatal only to aphids; consequently the following discussion of results will be devoted chiefly to this family of insects, and the effects of this substance on the other insects utilized will be noted only here and there.

(*a*) Effects of Quassiin Powder

At the outset a purified powder of quassia, already mentioned on page 509, was used. This powder is light yellow and is supposed to be largely quassiin. It is intensely bitter, has a faint odor, and is disagreeable to work with, for after a few moments, regardless of how carefully it is handled, a bitter taste is experienced which sometimes lasts half a day, and consequently a headache often results. It would thus seem that the odor, and probably the minutest particles of the powder suspended in the air pass into the nose and mouth and give rise to the sensation of having tasted it.

To determine whether the exhalation from the quassiin powder alone is sufficient to kill aphids, a watch glass was completely filled with the powder; then a wire screen was laid over the powder and a nasturtium leaf, bearing about 45 aphids (*Aphis rumicis*), was laid upon the screen

so that the aphids were against the wire screen but not in contact with the powder. Fifty minutes later most of the aphids were "stupid"; 5 hours later 2 of them were dead; and the following morning 15 were dead, and the others had crawled away.

At 11 a. m. leaves from nasturtiums, apple, ragweed, and snowball, all bearing many aphids (*Aphis rumicis*, *Aphis pomi* De Geer, *Macrosiphum ambrosiae*, and *Aphis viburniphila* Patch), were dusted with the quassiin powder. Forty-five minutes later most of the aphids were inactive, and by 4.30 p. m. practically all of them were dead.

At 12 noon leaves from mulberry and pear trees, bearing many fall webworms (caterpillars of *Hyphantria cunea* Dru.) were dusted with the quassiin powder. By 2.30 p. m. nearly all of the webworms were inactive, and by 4.30 p. m. all of them were apparently dead; the following morning at 10 o'clock all were still apparently lifeless, except a few which were slowly reviving from their "stupor"; two days later still most of them had revived and were as active as usual.

At 4 p. m. several mulberry leaves were cut into small pieces and then some of the quassiin powder was mixed with them; next, 20 medium-sized silkworms (larvæ of *Bombyx mori* L.) were placed upon the mixture of leaves and powder. Half an hour later three silkworms were apparently lifeless, and the others appeared weak and sick; they did not seem to eat the bits of leaves, but crawled away from them, and consequently it was necessary to confine them in a box with the poisoned food. The following morning all of them were apparently dead, and they never revived thereafter.

A microscopical examination shows that the minutest particles of the quassiin powder are sufficiently small to pass through the spiracles of aphids and into the tracheal trunks for some distance; but, before they can come into contact with the nervous system (supposing that this system is the tissue vitally affected), they must pass through the smaller tracheal branches and even then through the tracheal walls in order to come into contact with the nerve cells. Furthermore, it is scarcely possible that they pass even through the spiracles of aphids and fall webworms because the spiracles are well guarded by hairs (22, p. 104). In view of the preceding, it seems that the exhalations alone from this powder killed the aphids and silkworms employed and rendered the fall webworms inactive for about a day.

(*b*) Effects of Quassia Powder

The preceding experiments were repeated by dusting quassia powder upon aphids from nasturtiums and snowballs, and upon silkworms and fall webworms. During the first 24 hours no effects were observed, except that a few of the smallest aphids died and that the silkworms were rendered slightly "stupid" for a few hours, but the webworms apparently were not affected at all. Some of the aphids were even

buried in the powder; after a few moments they invariably came to the surface and crawled away from the powder without apparently being affected.

This powder is made from quassia chips finely ground. It has a very faint odor, but while handling it a person does not experience a bitter taste as he does while working with quassiin powder. The minutest particles of the powder are no larger than those of the quassiin powder, but the largest particles are considerably larger than those of the quassiin powder. While the particles of the quassiin powder adhere to one another considerably, those of the quassia powder do not.

(*c*) Effects of Water Extract of Quassiin Powder

A strong extract was secured by boiling for two hours 200 c. c. of water containing 1 gm. of the quassiin powder. When the mixture was filtered, the filtrate was not quite as clear as water; it emitted a very faint odor and had a bitter taste. When applied with an atomizer it seems that some of the fine spray carried by the air must have passed into the operator's mouth, because a bitter taste was always experienced whenever this solution was used as a spray.

To determine whether the exhalations or vapor from the preceding solution is alone sufficient to kill aphids, a 75-c. c. beaker was filled with this spray mixture. A wire screen was then laid over the liquid and a nasturtium leaf bearing many aphids was placed upon the wire screen so that the insects were near the liquid, but not in contact with it. Not one of the aphids apparently was affected.

To ascertain whether the quassiin contained in the preceding solution is volatile when heated, 50 c. c. of the solution were poured into a 100-c. c. retort and heated. It was found that the steam produced by heating the solution had no apparent effect upon the aphids (*Aphis rumicis* and *Macrosiphum liriodendri*) tested. The steam was odorless, and, when condensed, the resultant liquid was as clear as water. It was tasteless and lead acetate did not precipitate it, while the same compound slightly precipitated the quassiin solution. It is thus seen that the quassiin contained in the solution is nonvolatile, and therefore such solutions can not be used for fumigating purposes. Furthermore, it follows that the vapors arising from quassia extract solutions do not carry quassiin.

At 9 a. m. 508 aphids upon tulip-tree leaves were sprayed with quassiin solution. At 12 noon only a few of the aphids were dead, at 4 p. m. 90 per cent were dead, and the following morning all were dead. It was noted that a faint odor was emitted by the spray solution upon the leaves, and even when the leaves became dry a very faint odor resembling that of the quassiin solution was still given off.

On account of the long time required for the quassiin to kill the aphids, it is probable that this insecticide acted as a stomach poison. The spray solution might have passed through the stomata and epidermis of the

leaves, and when within the interior of the leaves it might have been imbibed through the proboscides of the aphids and then passed into their alimentary canals. To test this probability, 58 aphids on tulip-tree leaves were gently brushed into a wire-screen case, and at 8.30 a. m. they were sprayed with the quassiin solution; at 12.30 p. m. only a few of them were dead, but at 4.30 p. m. 88 per cent of them were dead. This experiment shows that the quassiin did not act as a stomach poison by passing from the interior of the leaves through the proboscides and then into the alimentary canals of the aphids, and it is unlikely that the aphids imbibed some of the solution on their bodies before they died. While tracing insecticides inside aphids, the senior writer has never seen the poisons either in the proboscis or in the alimentary canal. Sections also show that quassia-extract solutions do not pass into the interior of plants.

In the foregoing it is shown that neither the exhalations nor vapor from the quassiin solution kill aphids, and this insecticide when applied as a spray also does not act as a stomach poison; but there yet remain the two following possible ways in which it may exert its effects upon aphids: (1) The solution may enter the spiracles and come into contact with the nervous system or it may cause death by suffocation, or (2) some of the fine spray may be taken into the respiratory system while the aphids are being sprayed.

Regarding the first view, the senior writer (22, p. 103) has recently shown that nicotine-spray solutions (not containing soap) do not enter the spiracles of aphids, and it is shown on page 525 that quassia-extract solutions (not containing soap) also do not enter the spiracles. If it is granted that this solution does gain entrance through the spiracles but does not come into contact with the nerve cells, would it kill aphids within a limited time by cutting off the supply of oxygen? To test this possibility one sweet-pea plant and four nasturtium leaves, each bearing many aphids, were submerged in water for 5½ hours. A film of air surrounded the leaves, stems, and parts of the aphids, but it was gradually absorbed by the water, so that at the time at which the insects were removed from the water practically all of the air had been absorbed, except several minute bubbles which still adhered to the aphids. When removed from the water, one-half of the pea aphids had fallen from the plant to the bottom of the jar containing the water; they were apparently lifeless, while those remaining on the plant moved when touched. All of the nasturtium aphids exhibited signs of life when removed from the water. Within a short time the inactive aphids revived, and all of the submerged ones soon became normal. It is therefore evident that aphids are not easily suffocated.

To support the second view, three nasturtium leaves and two sweet-pea plants, each bearing many aphids, were submerged in the quassiin solution for half a minute. The solution did not adhere well to the leaves and

aphids, and the insects afterwards were apparently not affected. For this solution to be effective it must be sprayed upon the insects, and since it can not reach the nervous system in any form other than as a fine spray carried by the air, it is believed that death occurred as a result of some of the fine spray being taken into the respiratory system while the solution was being applied. This view agrees with the one that some of the fine spray which is carried by the air passes into the operator's mouth, thereby causing a bitter taste.

At this place should be mentioned quassiin extract as a stomach poison for bees and flies. A large quantity of quassiin, extracted from the quassiin powder and then dissolved in sugar sirup, was fed to 250 honeybees (*Apis mellifica* L.) in observation cases. At no time was a symptom observed which could be attributed to the effects of the quassiin, and these bees lived practically as long as controls fed sugar sirup not containing this insecticide. These results agree with those obtained by Illingworth (18, p. 160), who fed sweetened quassia-extract solution to flies (*Rhagoletis pomonella*). He says:

> The flies ate the sweetened, bitter liquid freely, but no harm came to them.

It should be noted, however, that Brande (3) in an early textbook states that quassia is an effectual stomach poison for flies.

(*d*) Effects of Water Extract of Quassia Chips

Fifty grams of quassia chips were soaked in 1,000 c. c. of water for 24 hours; this proportion is about equal to 44 pounds of chips to 100 gallons of water. At 8 o'clock many rose aphids, fall webworms, and larvæ of the potato beetle (*Leptinotarsa decemlineata* Say) were sprayed with the above solution; at 11 o'clock few of the aphids were apparently dead and many of the webworms were inactive; at 1 o'clock all of the aphids and webworms were apparently dead, but only a few of the former had fallen from the plants; all of the potato-beetle larvæ had fallen to the ground, some were apparently dead and the others were so affected that they could yet move their legs but could not crawl; at 4.30 o'clock all of the insects sprayed were apparently dead. The following morning several of the aphids and practically all of the potato-beetle larvæ had revived, while the webworms were slowly recovering from the effects of the spray. On the second day after being sprayed, most of the webworms had become normal.

(*e*) Effects of Soap-Solution Extract of Quassia Chips

In the preceding paragraph and on pages 512 to 513 it is shown that strong water extracts of quassia chips do kill aphids when properly applied, but it is also shown on pages 514 to 515 that weaker extracts containing soap solution are really more effective. As a rule, while the inefficiency of quassiin dissolved in water may be attributed to the poor

insecticidal properties of this substance and to the fact that water does not spread it well, the efficiency of it when dissolved in soap solution would seem to be due to the fact that the soap solution spreads it in such a manner that a larger amount of it may reach the nervous system. It now remains to be shown how it reaches the nervous system, for there is no other plausible way of explaining its effects on aphids.

Experiments in which a soap-solution extract of quassia chips was used, in the same manner as described on pages 514 and 515, demonstrate that the exhalations from this spray mixture do not kill aphids, and that the mixture does not act as a stomach poison when applied as a spray. On page 515 it is further shown that soap solution containing no quassia extract but the same amount of soap as employed in the soap-solution extract has no apparent effect on some aphids, and but very little on other aphids.

While the spray mixture was being applied, some of the fine spray might have been taken into the respiratory system and possibly came into contact with the nerve cells, but, comparing the effects of this spray mixture with that containing no soap, the writers are inclined to believe that a larger amount of the quassia extract is required in order to produce the results observed. Owing to the fact that soap solutions have weak surface tensions, they adhere well to the surfaces of plants and insects; they spread readily, and consequently should pass freely into the spiracles of insects. Under the following heading it is shown that they not only pass into most of the larger tracheæ but also come into direct contact with the nerve cells.

The senior writer (22, p. 92) attributed the abnormal behavior exhibited by aphids which had been sprayed with a solution of nicotine to motor paralysis, but at no time while using quassiin on aphids was a similar behavior observed. While nicotine acts quickly and causes pronounced symptoms, quassiin acts very slowly, and the behavior of aphids poisoned by it is so normal that the few abnormal reactions exhibited are generally overlooked. Soon after being sprayed with a nicotine solution, aphids remove their beaks from the plants and wander about considerably, and sooner or later they fall paresized from the plants, after which they soon die. Aphids sprayed with a solution of quassia extract are no more irritated than when they are sprayed with water. While being sprayed, they lie flat on the leaves, and later seldom remove their beaks from the plants; consequently they wander about little. Usually they do not begin falling from the plants till three or four hours after being sprayed, and by that time most of those that fall are dead. As a rule they die quietly with the beaks stuck into the plants, and in most cases it is necessary to touch them before being able to decide whether they are dead or alive. While practically all of the aphids sprayed with a nicotine solution fall from the plants before they die, not

more than one-half of those sprayed with a solution of quassia extract usually fall from the plants until several hours after they are dead.

The preceding symptoms exhibited by aphids do not indicate that the nervous system is the first tissue to be vitally affected, but a critical study of the behavior of pea aphids sprayed with a quassiin solution shows one symptom which indicates a nervous affection. Several sweet-pea plants bearing many aphids were sprayed with a solution containing a definite proportion of the extract from quassiin powder in water. An hour after being sprayed, a few of the aphids stood up and trembled vigorously for two or three seconds; afterwards they gradually became less active when touched and weaker until they died. The trembling behavior was never observed in unsprayed aphids.

2. HISTOLOGICAL METHODS OF TRACING QUASSIIN IN TISSUES

To determine, if possible, what tissue is vitally affected when aphids are sprayed with solutions containing extracts of quassiin powder and quassia chips, the insects, after being treated with these solutions, were fixed in a fluid containing a precipitant. By this means one or more constituents in each spray solution were precipitated wherever they had gone into the insects; and after carefully studying the microscopical sections made from these aphids, it was usually easy to trace the precipitated particles.

(*a*) Tracing Water Extracts of Quassiin Powder into Aphids

Of the few reagents that precipitate quassiin, not one of them precipitates it satisfactorily so that the above procedure might be followed. Owing to the unsatisfactory precipitation, it was necessary to add to the spray solution some chemical which under normal conditions is never used, in order that this chemical might be thrown down wherever the spray solution had carried it into the insect.

The senior writer (22, p. 101, 103) submerged aphids for 45 minutes in, and also sprayed them with, a nicotine solution colored with indigo-carmine. By using the above method it was found that the solution had passed into a few of the larger tracheæ of the aphids submerged, but never into the tracheæ of those aphids sprayed, and only once in the latter had a little precipitate lodged in a spiracle. These results indicate that any solution almost totally water sprayed upon aphids would not pass into the tracheæ, unless the permeability of this solution had been considerably increased, or its surface tension had been rendered very weak by the addition of some other substance not already in the solution.

Despite the supposition that water containing quassiin has practically the same permeability and surface tension as does water not containing this substance, it was desirable to know whether this solution would pass into the tracheæ. After failing to obtain a satisfactory precipitate by

mixing either lead acetate or tannic acid with the solution containing the water extract of quassiin powder (described on p. 520), 4 parts of the quassiin solution were added to 1 part of aqueous ferric-chlorid solution. Aphids submerged in this mixture for ½ minute, 30 minutes, and 40 minutes were then fixed in a fluid made in the proportion of 5 c. c. of absolute alcohol to 5 drops of tannic acid. A black precipitate is thrown down when this acid unites with ferric chlorid. After remaining in the mixture of alcohol and tannic acid an hour, the aphids were removed and were then placed into absolute alcohol to insure better fixation. Since this precipitate, as well as the other precipitates, do not adhere well to insects, no liquid was used for straightening the ribbons on the slides; the sections were pressed against the slides by using the fingers, and as alcohol easily removes such precipitates from sections, most of the sections were not stained, and these were left in the xylol only a sufficient time to remove the paraffin. Those sections stained were usually not reliable for tracing precipitates, because some of the precipitate had been lost while the slides were being run through the alcohols, and, furthermore, very often the stain masked the precipitate.

A study of the foregoing sections showed a small amount of black precipitate on the outside of the integuments of the aphids that had been submerged only one-half minute, but none was seen in the spiracles or in the tracheæ; however, in those aphids submerged for 30 and 40 minutes much more black precipitate was seen on the outside of their integuments, and occasionally a few small particles in the spiracles and in the tracheæ a short distance from the spiracles.

(*b*) Tracing Soap Solution Extracts of Quassia Chips into Aphids

Aphids on sweet peas and nasturtiums were sprayed so heavily with the soap-solution extract (1A) from quassia chips described on page 515 that the solution collected in drops around the legs of the aphids and had not all disappeared 3½ hours later, when the aphids and leaves were fixed. Some of these insects were sprayed with the solution colored with carmine acid; and the others with the solution not containing a stain. The former were fixed in absolute alcohol overnight, and the latter in the fixative described below. Absolute alcohol containing ferric chlorid ($Fe_2Cl_6 + 12\ H_2O$) readily precipitates the potassium in the soap solution; but since the water in the ferric chlorid dilutes the absolute alcohol, a good fixation does not result. To avoid this difficulty the ferric chlorid was melted and fused, thereby dehydrating it. Absolute alcohol was then saturated with the resulting cold melt, and after filtering the mixture an amber colored liquid resulted. When this liquid was mixed with the soap solution, a yellowish, flocculent precipitate was formed. Those aphids fixed in this fluid were afterwards well washed in pure absolute alcohol to remove the fixative and to insure better fixation.

A study of the sections from the above aphids shows that the precipitate did not adhere well to the tissues and, owing to its color, it is discernible in sections only with difficulty. Nevertheless, small particles of it were observed occasionally on the integuments and in the tracheæ, showing that a soap solution not containing a stain passes into the respiratory system of aphids when used as a spray.

Owing to the color and adhering ability of precipitated carmine acid, the sections from the aphids sprayed with the soap-solution extract colored with this stain are much more satisfactory to study. A careful study of them shows the following: Much of the red precipitate adheres to the outside of the integuments, but none of it has passed through them; much of it also lies in the spiracles and at various places in practically all the large tracheæ in the abdomen, thorax, and head, and in the bases of all the legs, but none was observed in the lumens passing through the proboscides. In the abdomens and bases of the legs the fat cells surrounding the tracheæ are generally stained red, indicating that the liquid had passed through the tracheal walls. At one place in a thorax a trachea, bearing some of the precipitate, runs along beside a large muscle which is also slightly stained. More or less precipitate was also observed in the tracheæ lying against the optic lobes, the brain, and thoracic ganglion; and occasionally it was noted that the colored liquid had passed through the tracheal walls and had stained the nerve cells near by. Only a few small particles of the precipitate were observed in the interior of the optic lobes and brain.

The preceding results indicate that the nerve tissue is the one vitally affected, because the spray solution does not seem sufficiently distributed in the other tissues to cause fatality, whereas only a few particles of any toxic substance in the brain and ganglia usually cause death.

SUMMARY

Throughout this investigation the experimental results obtained almost invariably support the results of the quantitative determinations. The data obtained pertaining to this portion of the work are as follows:

(1) Medium-sized quassia chips (samples 3 and 4, Table III) soaked for two hours in water yield during the first extraction about 60 per cent of their total soluble matter, but only about 15 per cent during the second extraction; if soaked for 24 hours, they yield during the first extraction about 60 per cent, but during the second extraction about 10 per cent. Experiments with first and second extracts always showed that the first extract was the more effective, but the ratio of effectiveness of the first to the second extract was only about 9 to 7; this is true for both water extracts and soap-solution extracts. In practical spraying neither one of the water extracts nor the second soap-solution extract was efficient, but the first soap-solution extract was sometimes efficient.

(2) Quassia chips boiled longer than four hours in water yield but little more extract than those boiled for just four hours, and the quantity obtained is about 1.5 times that obtained from chips soaked in water for 24 hours. Extracts from chips soaked in water are usually less effective than those from chips boiled in water, but not one of those tested would be efficient in practical work.

(3) The smaller the quassia chips and the finer the quassia powder used, the greater is the quantity of extract removed.

(4) The larger the volume of water used as a solvent, the greater is the quantity of extract removed; for example, 10 gms. of chips soaked for 24 hours in 3,000 c. c. of water yield 32.1 per cent more extract than 10 gms. soaked for the same period in 250 c. c. of water. The practical experiments well support this view.

(5) The solubility in water of the quassiin powder used in these experiments was found to be 1 to 3,000. In a 0.05 per cent sodium-carbonate solution, a soap solution (1.8 gm. of soap to 1,000 c. c. of water), and in a 0.05 per cent lye solution its solubility was, respectively, 3, 4, and 5 times as great.

The experimental results obtained with quassiin powder and quassia chips supported this view in only a general way. The sodium-carbonate solution extract was only slightly more effective than the water extract. The soap-solution extract and lye-solution extract were equally effective in the laboratory when applied as prepared; but when the former solution was diluted with soap solution and the latter solution with water, the dilutions containing the soap-solution extract were much more effective and also more economical, provided the soap was also added to the dilutions containing the lye-solution extract. Extracts from chips soaked in the solvents mentioned are more effective than those from chips boiled in these solvents. This seems to indicate that at a high temperature alkalies decompose quassiin, or render it insoluble.

The following results deal with the pharmacological effects of quassiin:

(1) A moderately bitter and practically ineffective extract was dissolved from commercially pure quassiin powder, leaving a residue whose water extract was intensely bitter and quite effective. The first extract corresponds to quassol, a supposedly inert and tasteless substance with a slight admixture of quassiin; the second extract corresponds exactly to pure quassiin.

(2) The exhalations alone from the quassiin powder killed aphids, but the exhalations from quassia chips, quassia powder, and those from solutions containing quassiin extract and quassia extract were ineffective. Quassia powder dusted upon insects is ineffective, while quassiin powder is quite effective, indicating that the exhalations pass into the respiratory system and that they then affect the nervous system. The minutest particles of either powder are sufficiently small to pass into the spiracles, but they do not cause death by closing the entrances of the tracheæ.

(3) Quassia and quassiin spray solutions, not containing soap, kill aphids when applied sufficiently strong. By the process of elimination it is concluded that death occurs as a result of some of the fine spray being breathed into the respiratory system while the aphids are being sprayed.

(4) The greater effectiveness of solutions containing soap is due to the weaker surface tension of such solutions, which pass freely through the spiracles and finally reach the nervous tissue, where they kill by slowly affecting the nerve cells.

(5) While nicotine acts quickly and causes pronounced symptoms, quassiin acts very slowly and causes but few symptoms, and these are never pronounced. While nicotine kills by paralysis, quassiin causes no noticeable paralysis, but aphids poisoned by it slowly become inactive and finally die in what is known as "coma" in the higher animals.

In conclusion, it should be stated that owing to the poor insecticidal properties of quassiin, quassia extract can never become a general insecticide for all aphids. Of course, the amount of extract to be used could be sufficiently increased so that the spray solution would perhaps be efficient on any particular aphid, but in most cases the expense would prohibit its use. The most effective formula (6B, first extract, Table IX) used by the writers was prepared by soaking 22 pounds of quassia chips in 100 gallons of fish-oil-soap solution (1.6 pounds of soap to 100 gallons of water) for 24 hours. This spray solution under the most favorable conditions was efficient on only two of the six species of aphids tested, but the results as recorded are comparable to those obtained by using nicotine-sulphate solution. Nevertheless, owing to the slow action of quassiin, this spray solution is much less reliable than is nicotine-sulphate solution, because the aphids sprayed have better opportunities to migrate, and should it rain a few hours after the solution has been applied its effectiveness would be greatly reduced, while such is not true for nicotine-sulphate solution. This spray solution, not including the cost of preparing it, is almost as expensive as nicotine sulphate solution (1:800 of soap solution). Formula 3A (Table IX), the one recommended against the hop aphis, was found efficient on only the nasturtium aphis, although it was sprayed upon six other species.

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A NURSERY BLIGHT OF CEDARS

By GLENN G. HAHN, *Scientific Assistant;* CARL HARTLEY, *Forest Pathologist;* and ROY G. PIERCE, *Forest Assistant, Investigations in Forest Pathology, Bureau of Plant Industry, United States Department of Agriculture*

INTRODUCTION

For at least 15 years nurserymen who raise red cedars (*Juniperus virginiana* L. and *J. scopulorum* Sarg. and their horticultural varieties) have lost large quantities of stock from a disease of unknown origin. As a result, several of the largest growers have been forced to abandon the raising of red cedar. While both of these cedars are undesirable for use in regions where apples (*Malus sylvestris*) are grown, on account of their ability to carry the very harmful rust of apples,[1] they have proved very desirable trees for planting in some of the drier regions where apples are not grown. The demand for them is sufficient to make their propagation of considerable importance in certain nurseries of the Middle West.

HISTORY OF THE DISEASE

In 1900 Dr. G. G. Hedgcock, of this Office, observed a *Phoma* sp. upon the smaller terminal branchlets of large trees of *Juniperus virginiana* in the vicinity of Nora, Nebraska. Later, in 1904, he took notes upon a serious disease of red-cedar nursery stock in Iowa and Minnesota, having found on the diseased material a fungus which he again referred to *Phoma* sp. and which he believed to be the cause of the condition. Specimens gathered in 1900 by Dr. Hedgcock show pycnidia and spores of a species of Phoma, but no nursery specimens observed in 1904 were preserved. In the spring of 1916 the writers, in ignorance of Dr. Hedgcock's observations, found a species of Phoma upon diseased *J. virginiana* fruiting on so many and such recent lesions that its parasitism was strongly indicated. Cultures were made by taking, with aseptic precautions, pieces of inner bark from recent lesions and planting them in agar. The cultures most commonly obtained in this way were indistinguishable on artificial media from the cultures made from spores of the fungus under suspicion. Numerous controlled wound inoculations were made, both with cultures from single spores and from the tissue plantings. In each series 50 to 100 per cent of the inoculations gave positive results. Positive inoculations were also obtained on nine other species of the

[1] *J. scopulorum* has not been previously reported as a host for the cedar-apple rust. In 1916, trees of this cedar, raised in Illinois from seed obtained in the Dakota Black Hills, and differing decidedly in habit and color from trees of *J. virginiana* of the same age, were found bearing numerous rust galls. The spore horns and teleutospores were identical with those described for *Gymnosporangium juniperi-virginianae* Schw. The specimens are in the collections of the Office of Forest Pathology (F. P. 25008) and in the Pathological Collections, Bureau of Plant Industry.

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genera Juniperus, Thuja, and Cupressus. The original organism was easily recovered from inoculated plants, and with red cedar the reinoculations gave positive results. The disease symptoms in the successfully inoculated plants were identical with those observed in diseased plants of *Juniperus* spp. in the nurseries. As many of the successful inoculations on *J. virginiana* were made at an Illinois nursery under normal summer conditions, there is every reason to believe that the *Phoma* sp. is the cause of the common red-cedar blight. The fungus has been obtained in quantity during 1916 from nurseries in Kansas,[1] Iowa, Illinois, and Pennsylvania (F. P. 18147, 18148, 18149, 25000, 25001, 25002, 25003, 25007).[2] The *Phoma* sp. found associated with a serious killing of small branchlets of red cedar in eastern Nebraska by Dr. Hedgcock in 1900 (F. P. 25006) has been found to be identical with the nursery organism under consideration in this paper.

The white cedars are not ordinarily subject to heavy parasitic loss in nurseries. However, serious loss has been observed in recently transplanted *Thuja orientalis* L. in a nursery in the Nebraska sand hills, with symptoms indicating a parasite as the cause. The ease with which positive results can be secured with inoculation on all the cedars tested indicates that, when any of them are grown in nurseries on a large scale under climatic conditions favorable for fungus attack, trouble from *Phoma* sp. is at least occasionally to be expected.

A more detailed description of the disease, the parasite, and the experimental evidence on which the foregoing conclusions are based, is presented in the following.

DESCRIPTION OF THE DISEASE

In the case of *J. virginiana* the disease works throughout the growing season in both seedling and transplant beds. Injury seldom occurs after the trees are four years old. At any time before the end of the third year the disease may become epidemic, often destroying entire beds. The ultimate appearance of affected stock (Pl. 60, A) is much like that of stock killed in other ways, as for instance, by drouth or transplanting shock. However, at earlier stages a careful examination will show clearly the parasitic character of the trouble. At the bases of killed parts of the plants which have been dead for only a short time are found regions whose color gives evidence of having been dead longer than the parts beyond. These old lesions commonly are either much bleached, or have a purplish or grayish cast, and are quite easily distinguished from the browner color of the recently killed parts. Frequently definite lesions are found on stems which are still living or which have been only recently killed. On woody stems these lesions are usually found at the point of attachment of laterals which have been dead for a considerable

[1] Specimens from Professors C. A. Scott and L. E. Melchers, of the Kansas State Agricultural College.
[2] Numbers refer to collections in the Office of Forest Pathology.

time. It seems to be a common thing for the parasite to infect and kill laterals, and then to enter the main stems through the bases of these laterals. As the fungus travels longitudinally much faster than transversely, it frequently happens on plants older than 2 years that the lesions starting at the bases of killed laterals extend vertically for several centimeters and, before the main stem is girdled, kill other laterals above and below the one originally infected. On cutting into lesions on the older stems both the cambium and the underlying wood are found to be involved by a dark-brown discoloration. On stems old enough to have developed considerable resistance to the transverse extension of infections which have entered from killed laterals the longitudinal lesions develop into definite sunken cankers, and further growth on the unaffected side results in a flattening of the stem.

Lesions on woody stems are often limited, and partial healing has been observed, indicating ultimate recovery. Swollen growth of the stem above the point of girdling, such as is reported for *Phoma abietina* Hartig [1] (*Fusicoccum abietinum* Prill. et Delacy) upon silver fir, and *Phoma pithya* Sacc.[2] upon Douglas fir has not occurred upon any of the species of Juniperus or species of Thuja on which the parasitism of this species of Phoma has been observed, and is not to be expected, in view of the longitudinal extension of the lesion.

It has been frequently evident in the inoculation work that conduction of water is at least at first not seriously interfered with by the lesions. Terminals often remain apparently healthy for weeks after the stems below them have been girdled. Under greenhouse conditions it sometimes happens that the terminals remain healthy until killed as a result of inclusion in the lesion, even though the lesion may have first girdled the stem 10 or 15 cm. below the tip. The upward progress of the lesions is very much more rapid than their downward progress. In some cases, under greenhouse conditions, the fungus has been found exuding spore horns from tissue not yet definitely discolored.

The distribution of the disease in the nursery beds is very irregular, appearing to spread from definite foci. In broadcast seed beds seedlings are in direct contact with each other, so that this type of spread is easily explained. Two nurseries in western Kansas have raised red cedar with distinctly less trouble from the disease than has been reported from nurseries farther east. This, and the report of one of the Middle West nurserymen that the disease is most serious in wet seasons, indicates the importance of a moist climate as a factor favoring the disease. The sticky character of the spores of the parasite points to water rather than to wind as the most important means of dissemination. The distribution of the disease in parallel beds of *J. virginiana* and *J. scopulorum*

[1] HARTIG, R. TEXT-BOOK OF THE DISEASES OF TREES. [Trans. by William Somerville.] p. 138–139. London, 1894.

[2] TUBEUF, Karl von. DISEASES OF PLANTS INDUCED BY CRYPTOGAMIC PARASITES. [Eng. ed. by W. G. Smith.] p. 466. London, New York, and Bombay, 1897.

indicates greater susceptibility of the former under Middle West conditions. The disease, so far as found by the writers, has been limited to nurseries. Its prevalence in nurseries is presumably in part due to the favorable conditions prevailing for the dissemination of the fungus in crowded beds. Transit of spores is not only made easy by the short distance between plants but the production of spores is apparently favored by the moisture of the air in the beds. Spore horns are most commonly found in the presumably moister air layer next to the soil surface.

THE PARASITE

The causal fungus is referred for the present to the genus Phoma. It forms definite pycnidia of a rather unusual type upon both stem and leaves, and no attempt will be made to name it definitely until work now in progress with it can be completed. The pycnidia, which are at first innate, are black, scattered, globose to conical or truncate, rarely more than 0.5 mm. in diameter, and have the somewhat unusual habit of breaking through the epidermis in the early stages of their growth, commonly before the spore-bearing cavity is differentiated from the rest of the tissue. The cavity subsequently develops in the basal portion of the pycnidial mass, both its upper and lower surfaces being spore bearing. The spores are hyalin, continuous, ellipsoid to oblong, sometimes very slightly unilateral, guttulate, 7.7 to 12.1 by 1.8 to 3.8 μ, commonly 9 to 10.5 by 2.5 to 3.0 μ (measurements of 50 spores from different sources). The basidia are hyalin, unbranched, filiform, 12 to 15 μ long. The spores are extruded under moist conditions in gelatinous tendrils from 1 to 3 mm. long, and become brittle on drying (Pl. 61). These emerge through definite ostioles, necessarily long and chimney-like in pycnidia which have a large amount of pseudoparenchyma lying above the spore cavity. While the pycnidia are mostly 1-celled, in many of those upon the stem one or more rudimentary partitions arise from the floor of the cavity, this morphological character indicating relationship with plurilocular genera.

The fungus grows well on prune or corn-meal agar, and stains the former a dull orange-red, with the formation in the medium of red crystals superficially like those obtained by Hawkins and Stevens[1] from their pigment "B" in Endothia cultures. Fruits are sparingly obtained on prune or corn-meal agar, but more abundently in corn-meal flasks. No ascigerous stage has been so far observed.

INOCULATION EXPERIMENTS

In all of the inoculation experiments, 2- or 3-year-old cedar plants were used. The parts to be inoculated were first thoroughly cleaned with a cotton swab and 1 to 1,000 mercuric-chlorid solution. A wound was then made and mycelium inserted from an agar culture. In all, 11

[1] Hawkins, L. A., and Stevens, N. E. Endothia pigments. I. *In* Amer. Jour. Bot., v. 4, no. 6, p. 336–353. 1917.

different sets of inoculations were made, four of which were in outdoor nursery beds in Illinois and Michigan during June and August, and the rest in greenhouses in Illinois and at Washington, D. C., under both summer and winter conditions. In most of the experiments the inoculations were protected by wrapping with raffia after inoculation (Pl. 61, A); one or two of the earlier ones were protected instead by moist cotton and oiled paper. In a few of the greenhouse experiments moist chambers were used. In all tests control plants were cleaned, wounded, and subsequently protected in exactly the same way as those inoculated. The results of the inoculations with *Phoma* sp. on *J. virginiana* are summarized in Table I.

TABLE I.—*Results of inoculation experiments with Phoma sp. on 3-year-old transplants of Juniperus virginiana*

Variable factor.	Condition.	Number of inoculations.	Percentage infected.	Number of control wounds	Percentage infected.
Source of inoculum.	With cultures from diseased tissue plantings: Original.	87	75	51	0
	With cultures from diseased tissue plantings: Reisolation.	6	50	6	0
	Single spore cultures: Original	38	92	40	0
	Single spore cultures: Reisolation	6	100	6	0
Method of inserting inoculum.	In deep slits in bark	82	87	56	0
	In slits in outer bark (not penetrating cambium).	26	38	23	0
	In punctures	29	97	24	0
Location of plants.	Greenhouse	94	84	74	0
	Nursery beds	43	70	29	0
	Total	137	80	103	0

The successful inoculations were commonly found to have made perceptible progress into surrounding healthy tissues within five days after the insertion of inoculum. In all cases where moist chambers were used, and in most of the greenhouse experiments without moist chambers, the spore horns characteristic of *Phoma* sp. developed on the lesions (Pl. 61). Many of these spore horns were examined microscopically and their identity confirmed. In some cases the spore horns appeared within two weeks after the making of the inoculation. Infections resulting from inoculations on laterals extended down the lateral into the main stems, just as natural infections appear to do in the field. The control wounds, some of which were on the same plants as the inoculations and some on uninoculated plants, not only showed no signs of infection but promptly healed over.

An additional control was given the experiments by the inoculation results with other fungi. In the earlier experiments with *Phoma* sp. parallel inoculations were made with two other organisms which occurred in the cultures from diseased tissue. None of these parallel inoculations

were successful. They included (1) four deep slit inoculations with agar cultures of *Epicoccum* sp. with corresponding number of controls. This species of Epicoccum produced roundish to ellipsoid, dark, olivaceous, continuous spores, with reticulated surfaces, and in addition short, blunt protuberances. The long diameter of these spores varies from 20 to 28 μ. The form obtained agrees with *E. granulatum* Penzig described upon the twigs of *Acer pseudoplatanus* Kinn.[1]

(2) Eight deep slit inoculations with a species of Phyllosticta and four controls made in the same manner. This form was found commonly associated with the *Epicoccum* sp. upon blighted branchlets, together with *Alternaria* sp. and *Pestalozzia funerea* Desm. It is distinct from the species of Phoma that causes the red-cedar blight, and produces a globose, uniformly thin-walled, black pycnidium opening by a very definite pore through which a mass of spores ooze from a single chamber. These spores are ovoid to ellipsoid, nonguttate, 4.5 to 8 by 2.5 to 4 μ. Since this form was found only upon the needles rather than on the stems, it is assigned to Phyllosticta instead of Phoma. Alternaria and Pestalozzia, though occurring commonly, were not tested. Inoculations with *Pestalozzia* spp. are now in progress.

Inoculations were also made with the parasitic *Phoma* sp. on hosts other than *Juniperus virginiana* as follows: In the greenhouse on September 25, 1916, deep slit inoculations were made upon young potted plants of *Thuja occidentalis* L. and *T. orientalis* L. and upon *J. barbadensis* L. and *J. pachyphloea* Torr. The mycelium of single-spore cultures was used. All of these inoculations were successful. With the *T. occidentalis* there was a tendency for the blight to become limited and the lesions to callus over, but with *T. orientalis* in every case (eight inoculations) the stem was girdled and the upper part killed (Pl. 60, B). Upon the killed parts of the *T. orientalis* placed under a bell jar the pycnidia and characteristic spores of *Phoma* sp. were produced.

Later tests upon a wider variety of hosts include successful inoculations, with single spore cultures freshly isolated, upon *Juniperus communis* L., *J. communis sibirica* (Burgsd.) Rydberg, *J. prostrata* Pers., *Cupressus glabra* Sudworth, and *Thuja plicata* Don. Negative results were obtained upon *Libocedrus decurrens* Torr. and *Chamaecyparis lawsoniana* (Murr.) Parl. Whether the *Phoma* sp. will give positive results upon the eastern species of Chamaecyparis has not been determined.

CONTROL EXPERIMENTS

Spraying, the most promising preventive measure, has been tested by a commercial nurseryman thus far with rather uncertain results. The fungicides used were commercial lime-sulphur solution and Bordeaux

[1] LINDAU, Gustav. FUNGI IMPERFECTI: HYPHOMYCETES. p. 599. Leipzig, 1909. (Rabenhorst, Ludwig. Kryptogamen-Flora von Deutschland . . . Aufl. 2, Bd. 1, Abt. 9, Lfg. 114.)

mixture, with the addition of flour as an adhesive, in part of the experiments. The tests were not started until the disease had appeared in the beds. Experiments are planned with soap as an adhesive, to begin earlier in the season. Difficulty is anticipated in entirely controlling the disease in the nursery with any fungicidal treatments, because of the fact that even a single infection on a young plant is commonly fatal, in contrast to diseases of the leafspot type. Furthermore, infection may apparently occur at any time during the entire growing period.

As inoculations show that various conifers may serve as hosts for *Phoma* sp., sanitary measures should include removal of all dead plants or plant parts of other species of white or red cedars, as well as those seriously attacked. The promptness with which spores appear in moist weather emphasizes the need for prompt action if sanitation is to be of value. Spacing the plants farther apart, and taking care to avoid wounds in transplanting or cultivating, should also tend to decrease loss from the disease.

SUMMARY

(1) A disease of hitherto unknown origin has for years caused great loss to growers of red cedar in nurseries. It is primarily a disease of young plants, trees over 4 years old being seldom attacked under nursery conditions.

(2) A species of Phoma occurs commonly on the lesions. Its parasitism on 2- to 3-year-old plants of six species of Juniperus, three species of Thuja, and one species of Cupressus has been proved by inoculation at wounds. Control plants with similar wounds remained healthy. The fungus has been recovered from inoculated *J. virginiana*, and successful reinoculations have been made with it.

(3) The fungus has now been obtained from Kansas, Nebraska, Iowa, Illinois, and Pennsylvania. The first known collection was made in 1900.

(4) Spraying with commercial lime-sulphur solution and Bordeaux mixture has given little indication of their value as a control measure in incomplete tests so far made.

PLATE 60

A.—A 2-year-old seedling of *Juniperus virginiana* growing under field conditions, typically affected by red-cedar blight. The light-colored parts are the ones which have been killed. × ½.

B.—*Thuja orientalis: a*, inoculated at wounds in outer cortex with single spore cultures of *Phoma* sp.; *b*, control. Location of wound indicated by X. The killed parts of the inoculated plants are indicated by a shriveled condition and light color. When placed under a bell jar, fruits of the *Phoma* sp. were obtained on the killed parts.

B
b
a
A

A
B

PLATE 61

Spore horns of *Phoma* sp. upon *Juniperus virginiana* resulting from inoculation with single spore cultures under greenhouse conditions. In Figure A the raffia wrapping indicates point of inoculation and shows the method by which most of the inoculations were protected. × 3.6.

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FORMATION OF "BLACK ALKALI" (SODIUM CARBONATE) IN CALCAREOUS SOILS

By J. F. BREAZEALE,

Biophysical Investigations, Bureau of Plant Industry, United States Department of Agriculture

INTRODUCTION

It is unfortunate that the term "alkali," when used to designate an accumulation of water-soluble salts in the soil, has come into such common use in the United States. In this paper, this term will be adhered to out of deference to common custom. The term will be used to designate sodium chlorid, sodium sulphate, sodium carbonate, or any of the other water-soluble salts of the soil. As is well known, the term "black alkali" originated from the fact that sodium carbonate acts upon the organic matter of the soil and produces a dark-colored solution.

The writer is aware of the fact that the presence of calcium carbonate is not necessary in all cases to explain the formation of sodium carbonate. In the decomposition of the basalts, alkaline carbonates are likely to be formed. These carbonates may be transported and may reappear in other areas. The alkaline marshes around Klamath, Oreg., are examples of this type of alkali that quite likely did not form in that place. It is the purpose of this paper to discuss only one specific phase of alkali formation, and that is that which takes place when sodium salts are present in a calcareous soil.

With the exception of an adequate water supply, the presence and accumulation of alkali is probably the most important problem that confronts the man engaged in farming under irrigation in the arid and semiarid regions of the West. The successful reclamation of desert lands is by no means an easy matter, and the handling of the soluble salts that have accumulated in the soil during the centuries that it has been lying in this arid condition offers many difficult problems.

As ordinarily used, the term "alkali" consists chiefly of the salts of sodium, together with in lesser amounts the salts of calcium and mag-

nesium. In this paper the term will be used to include all the water-soluble salts of the soil, whether organic or inorganic.

The alkali tolerance of the plant varies widely. For instance, a plant may thrive in a saturated solution of gypsum and be killed by 1 part per million of copper, or even by lesser amounts of some of the more toxic organic salts. The accumulation of alkali in the soil, therefore, in sufficient amounts to make agriculture impossible does not necessarily mean the accumulation of the salts of sodium, calcium, and magnesium.

In 1892, Dorsey (3)[1] estimated that about 847,000 acres of the irrigated land in the United States had already been lost by alkali accumulation. He placed a value of $50 an acre on this land, and calculated a loss of $42,000,000 on account of alkali accumulation. A valuation of $50 an acre seems reasonable, as this would hardly pay for the average reclamation and water right. This was 14 years ago and the evil has been increasing year by year since that time; $100,000,000 would probably not now cover the loss sustained by alkali during our brief experience in irrigation agriculture.

The loss of land by alkali accumulation might well be divided into two distinct classes: The first, or greatest loss, generally occurs when the soils are first brought under irrigation. Water is applied to the soils on the benches or higher levels, usually in excessive amounts, and this dissolves out the salts that have accumulated in the soil while in a desert condition. The water, carrying with it the salt, gradually finds its way to the lower levels and to the lower drainage basins, and upon evaporation leaves the dissolved salts on, or near, the surface. These salts are ordinarily largely sodium chlorid, sodium sulphate, sodium carbonate, and sodium bicarbonate This seepage takes place when there is an abundance of water and drainage from the higher to the lower levels, and it is probably responsible for 90 per cent of the loss that has been sustained in the irrigation projects of the United States up to date.

The alkali accumulation, which might be considered as secondary, is much slower and takes place upon the bench lands, as well as upon the lower levels, and also upon many areas where there is a limited amount of irrigation water, and no drainage or seepage. This phase of alkali accumulation will be taken up later.

FORMATION OF "BLACK ALKALI"

In the arid and semiarid regions of the West, where alkali conditions abound, the presence of calcium carbonate, or carbonate of lime, is so common that it has been termed by Dr. Hilgard "a standing characteristic" of alkali soil. In a great many cases, although the carbonate is not in evidence upon the surface of the soil, it may be found from a few inches to a few feet below the surface, acting as a cementing material in the troublesome hardpan. This hardpan usually occurs at the lower

[1] Reference is made by number to "Literature cited," p. 589.

edge of the moisture plane, or where the moist soil of the surface shades into the dry subsoil. While it is quite likely that capillarity had little or nothing to do in the formation of this hardpan, which occurred under conditions of limited rainfall, it is, however, usually within easy reach from the surface of the capillary pull which would occur in a saturated soil, especially under conditions of irrigation. The importance of this calcareous hardpan in the study of the formation of black alkali will be brought up later.

Of all the alkali elements existing in this area, sodium, occurring as sodium chlorid, sodium sulphate, sodium carbonate, or sodium bicarbonate, and sodium nitrate, is the most common. This is due to the fact that soils originated largely by the evaporation of marine lagoons or landlocked seas, or were derived primarily from the so-called granites or more properly, diorite (soda-lime feldspar and hornblende). In these same soils, except in cases where a too high salt content prohibits activity, nitrification is usually rather intense. The presence and accumulation of nitrates, from this as well as from other sources, is usually noticeable in such cases.

Sodium carbonate (black alkali) is frequently met with in this area. As this is the most toxic salt that exists in appreciable amounts in alkali soils, its origin has created a good deal of speculation. It seems probable that all cases of black alkali are not due to the processes of rock disintegration. While the toxic action of sodium carbonate upon plants is much greater than that of sodium bicarbonate, they will not be differentiated in this discussion. It must be remembered that sodium bicarbonate is formed from sodium carbonate by the addition of carbon dioxid. Any cause which will liberate the carbon dioxid, such as the precipitation of the salt upon the surface by the evaporation of the water in which it is dissolved, will tend to convert the bicarbonate to the carbonate. The natural tendency of the bicarbonate is to become a carbonate, and, as carbon dioxid exists in all soils in appreciable amounts, it seems probable that the primary step in the formation of black alkali is often the formation of sodium carbonate.

REACTION BETWEEN SODIUM SALTS AND CALCIUM CARBONATE

It is well known that sodium salts will react with calcium carbonate, with the formation of sodium carbonate or bicarbonate and the corresponding calcium salt. The extent of this reaction and its bearing upon the formation of black alkali in nature has been taken up in this investigation.

Cameron (1) has described the probable formation of different types of alkali, and later Seidell (2), working under his direction, studied the reaction between sodium chlorid, sodium sulphate, and calcium carbonate. They drew air through the solutions until they had reached equilibrium and determined the amounts of sodium bicarbonate thus formed.

Hilgard, working with Webber, and later with Jaffa, determined the amounts of sodium bicarbonate formed when a stream of carbon dioxid was passed through solutions of sodium sulphate and sodium chlorid in contact with an excess of calcium carbonate (6, p. 449–451).

The solubility of calcium carbonate in pure water is about 10 parts per million, while in the presence of carbon dioxid its solubility is increased many times. In boiled distilled water calcium carbonate may be titrated, phenolphthalein being used as an indicator. However, the amount of carbon dioxid that usually occurs in ordinary distilled water is sufficient to make such a titration impossible. In such a case the titration with methyl orange as an indicator will, of course, give the amount of lime.

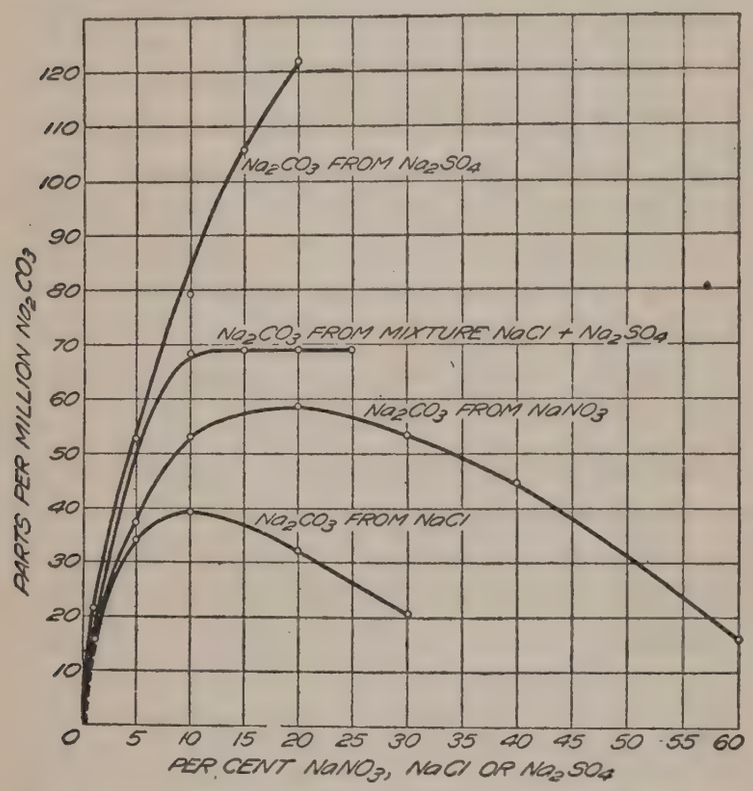

FIG 1.—Graphs of the sodium carbonate formed from reaction of calcium carbonate (solid phase present) with sodium chlorid, sodium nitrate, or sodium sulphate.

In this investigation the results of the reactions of sodium nitrate, sodium chlorid, and sodium sulphate with calcium carbonate, which react with phenolphthalein, are figured as sodium carbonate, while all titrations which react with methyl orange are figured as sodium bicarbonate. While it is realized that this is not strictly accurate, from the standpoint of a physical chemist, yet it is sufficiently accurate for the purposes of this investigation.

Occasional samples of a salt, especially sodium chlorid and sodium sulphate, were found to be slightly acid. This caused a great deal of trouble until the cause was discovered. Afterwards all salt solutions were neutralized with sodium hydrate before beginning the experiments.

This work was done at Riverside, Cal., and apparatus for the accurate control of temperature was not at hand. The work was carried on at room temperatures, with a considerable variation between night and day. The determinations, therefore, must not be understood as solubility measurements, but simply laboratory studies to be applied to field conditions near by.

The formation and the accumulation of nitrates and their effect upon plants has recently been given much attention, especially by the Califor-

nia, Colorado, and Utah Experiment Stations. Owing to the interest in this subject and in the injurious effects of continued applications of sodium nitrate as a fertilizer to Citrus groves, the reaction of sodium nitrate and calcium carbonate was first considered.

Solutions of sodium nitrate in graduated concentrations (given in Table I) were prepared with boiled distilled water. These were put in shaker bottles, with about 1 gm. of calcium carbonate in each bottle, tightly stoppered, and shaken for several days, or until they had reached equilibrium. Special effort was made to keep carbon dioxid out of the solution, but the opening of the bottle for the purpose of titrations, etc., made it impossible to keep it entirely out. As the saturation point of sodium nitrate increases noticeably with an increase of temperature, 60 per cent was taken as approximately representing the average condition of saturation.

When equilibrium was reached, aliquots were drawn off and titrations made for carbonates, with phenolphthalein as an indicator. The titration in distilled water, which was, of course, due to calcium carbonate was subtracted from each of the other titrations where sodium nitrate was present. This difference was then calculated as sodium carbonate.

These results are shown in Table I and figure 1.

TABLE I.—*Reaction between sodium nitrate and calcium carbonate*

Solution No.	Percentage of sodium nitrate.	Quantity of *N*/20 sulphuric acid for 100 c. c. of solution.	Parts per million of sodium carbonate formed.	Solution No.	Percentage of sodium nitrate.	Quantity of *N*/20 sulphuric acid for 100 c. c. of solution.	Parts per million of sodium carbonate formed.
		C. c.				*C. c.*	
1	0	0.3	0.0	5	20	1.4	58.3
2	1	.6	15.9	6	30	1.3	53.0
3	5	1.0	37.1	7	40	1.15	45.0
4	10	1.3	53.0	8	60	.6	15.9

Solutions of sodium chlorid and sodium sulphate and mixtures of equal parts of sodium chlorid and sodium sulphate were prepared and run in the same way as with the sodium nitrate. These results are shown in Tables II, III, and IV and figure 1.

TABLE II.—*Reaction between sodium chlorid and calcium carbonate*

Solution No.	Percentage of sodium chlorid.	Quantity of *N*/20 sulphuric acid for 100 c. c. of solution.	Parts per million of sodium carbonate formed.	Solution No.	Percentage of sodium chlorid.	Quantity of *N*/20 sulphuric acid for 100 c. c. of solution.	Parts per million of sodium carbonate formed.
		C. c.				*C. c.*	
1	0	0.3	0.0	4	10	1.05	39.8
2	1	.6	15.9	5	20	.9	31.8
3	5	.95	34.4	6	30	.7	21.2

TABLE III.—*Reaction between sodium sulphate and calcium carbonate*

Solution No.	Percentage of sodium sulphate.	Quantity of *N*/20 sulphuric acid for 100 c. c. of solution.	Parts per million of sodium carbonate formed.	Solution No.	Percentage of sodium sulphate.	Quantity of *N*/20 sulphuric acid for 100 c. c. of solution.	Parts per million of sodium carbonate formed.
		C. c.				*C. c.*	
1.....	0	0.3	0.0	4.....	10	1.8	79.5
2.....	1	.7	21.2	5.....	15	2.3	106.0
3.....	5	1.3	53.0	6.....	20	2.6	122.0

TABLE IV.—*Reaction between mixtures of equal parts of sodium chlorid and sodium sulphate and calcium carbonate*

Solution No.	Percentage of mixture.	Quantity of *N*/20 sulphuric acid for 100 c. c. of solution.	Parts per million of sodium carbonate formed.	Solution No.	Percentage of mixture.	Quantity of *N*/20 sulphuric acid for 100 c. c. of solution.	Parts per million of sodium carbonate formed.
		C. c.				*C. c.*	
1.....	0	0.3	0.0	5.....	15	1.6	68.9
2.....	1	.6	15.9	6.....	20	1.6	68.9
3.....	5	1.3	53.0	7.....	25	1.6	68.9
4.....	10	1.6	68.9				

In the reaction $NaNO_3 + CaCO_3 \rightleftarrows Na_2CO_3 + Ca(NO_3)_2$, at a maximum of about 20 per cent of sodium nitrate there is a possibility of a formation of about 58 parts per million of sodium carbonate.

In the reaction $2NaCl + CaCO_3 \rightleftarrows Na_2CO_3 + CaCl_2$, at a maximum concentration of about 10 per cent of sodium chlorid there is a possibility of a formation of about 40 parts per million of sodium carbonate.

In the reaction $Na_2SO_4 + CaCO_3 \rightleftarrows Na_2CO_3 + CaSO_4$, at the saturation point of sodium sulphate there is a possibility of the formation of about 122 parts per million of sodium carbonate under the conditions of this experiment.

The reactions just described are what might be termed the reverse reactions of those commonly considered when these salts are brought together. With sodium chlorid and calcium carbonate, for example, the reaction might be written $CaCl_2 + Na_2CO_3 \rightleftarrows CaCO_3 + 2NaCl$; or calcium chlorid and sodium carbonate in equilibrium with calcium carbonate and sodium chlorid. No matter which combination of salts is used, the resulting system will be exactly the same, and in the reaction last described there would still be about 40 parts per million of sodium carbonate left after the reaction had run to an end.

The drop in the curves, when sodium nitrate and sodium chlorid are used, as the saturation point is approached, is noticeable. This drop will be seen in all the curves outlined in this paper wherever a reaction takes place between calcium carbonate and sodium nitrate or sodium chlorid. This is not the case with sodium sulphate. The curve with this salt rises uniformly until the saturation point is reached. This fact will be explained later.

EFFECT OF SOLUBLE LIME SALTS UPON THE FORMATION OF SODIUM CARBONATE

The quantity of sodium carbonate formed in the reaction of calcium carbonate with sodium sulphate is relatively large in comparison with that formed with sodium nitrate or sodium chlorid. It was suggested that this might be due to the fact that in the reaction with sodium nitrate and sodium chlorid very soluble salts of lime, calcium nitrate, and calcium chlorid are formed, while with sodium sulphate a relatively slightly soluble salt, gypsum, is formed. This has a practical significance from the fact, as first advised by Dr. Hilgard, that the application of gypsum will improve soils containing too much black alkali. This is simply a reversal of the reaction considered above, as follows: $Na_2CO_3 + CaSO_4 \rightleftarrows Na_2SO_4 + CaCO_3$.

The following tables and curves will show the concentration of the soluble salts of lime that are required to stop the reaction at its maximum.

TABLE V.—*Reaction between 20 per cent solutions of sodium nitrate and calcium carbonate in the presence of calcium nitrate*

Solution No.	Percentage of calcium nitrate.	Parts per million of of sodium carbonate formed.	Solution No.	Percentage of calcium nitrate.	Parts per million of of sodium carbonate formed.
1	0.0	74.2	6	0.150	7.9
2	.025	34.5	7	.200	5.3
3	.050	21.2	8	.400	2.6
4	.075	15.9	9	.800	Trace.
5	.100	10.6	10	1.000	0

TABLE VI.—*Reaction between 10 per cent solutions of sodium chlorid and calcium carbonate in the presence of calcium chlorid*

Solution No.	Percentage of calcium chlorid.	Parts per million of sodium carbonate. formed.	Solution No.	Percentage of calcium chlorid.	Parts per million of sodium carbonate formed.
1	0.0	53.0	5	0.8	Trace.
2	.1	7.9	6	1.2	Trace.
3	.2	2.6	7	1.6	Trace.
4	.4	Trace.	8	2.0	Trace.

TABLE VII.—*Reaction between 20 per cent solutions of sodium sulphate and calcium carbonate in the presence of calcium sulphate*

Solution No.	Percentage of calcium sulphate.	Parts per million of sodium carbonate formed.	Solution No.	Percentage of calcium sulphate.	Parts per million of sodium carbonate formed.
1	0.0	122.0	4	0.105	37.0
2	.026	95.4	5	.210	23.8
3	.052	69.0			

Calcium nitrate was added to 20 per cent solutions of sodium nitrate in amounts shown in Table V, and these solutions were shaken up with an excess of calcium carbonate until they had reached equilibrium. The sodium carbonate was then determined.

Calcium chlorid was also added to 10 per cent solutions of sodium chlorid, and calcium sulphate to 20 per cent solutions of sodium sulphate in the same way. The curve with calcium chlorid follows very closely the curve with sodium nitrate. Eliminating for the present other modifying factors, it will be seen that in the presence of 0.5 per cent of either of the soluble lime salts, calcium chlorid or calcium sulphate, the quantity of sodium carbonate formed from the reaction of calcium carbonate with sodium chlorid or sodium nitrate, is very slight. In other words, if such reactions are responsible for the formation of normal sodium carbonate or black alkali in the soil, and it will be shown later that such reactions unquestionably do take place, even in the presence of the carbon dioxid of the soil, it is an essential condition that the calcium-chlorid content of the soil solution be reduced below 0.2 per cent and the calcium nitrate content below 0.5 per cent. The removal of the calcium chlorid and the calcium nitrate under natural conditions might result either from drainage or from surface evaporation. In the latter case the salts would be brought to the surface in solution and would accumulate as a crust or efflorescence. This is exactly what happens in nature. The calcium chlorid, or "slick spots," which are so often mistaken for black alkali and which are so common in the West, are no doubt formed in this way.

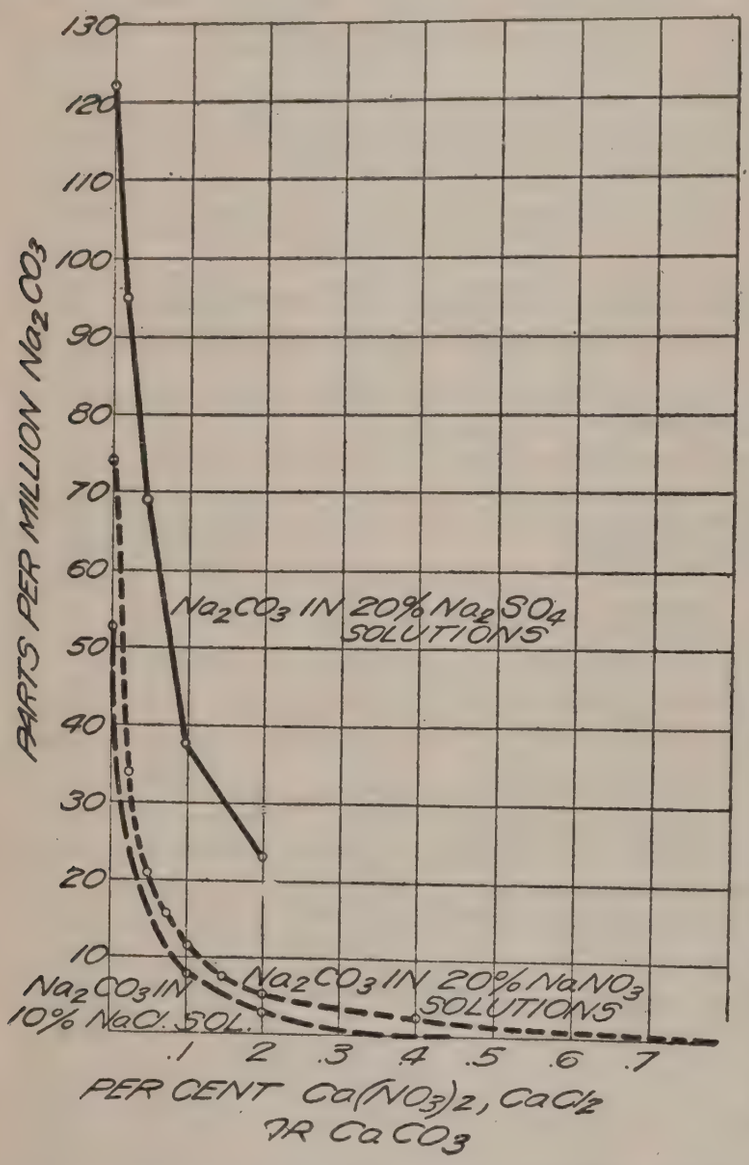

FIG. 2.—Graphs showing the depression of sodium carbonate formed by the reaction of calcium carbonate with sodium chlorid, sodium nitrate, or sodium sulphate when a soluble calcium salt containing a common anion is added.

On the other hand, there is an appreciable reaction between sodium sulphate and calcium carbonate, even in a saturated solution of calcium sulphate, as is shown in Table VII. The data in Tables V, VI, and VII are shown graphically in figure 2.

EFFECT OF GYPSUM UPON THE FORMATION OF SODIUM CARBONATE

As the soils of the West, as well as many of the irrigation waters, frequently contain gypsum in appreciable amounts, the reaction between the alkali salts sodium nitrate, sodium chlorid, and sodium sulphate with calcium carbonate usually takes place in the soil in the presence of more or less calcium sulphate. Tables VIII, IX, and X and figure 3 show the effect of this salt upon the formation of black alkali. As outlined in the tables, calcium sulphate was not added in excess, but a saturated solution containing 2.1 gm. per liter was used in preparing the different numbers. This was necessary in order to have a definite amount of calcium sulphate in the solutions, as the solubility of this salt increases very rapidly in the presence of certain sodium salts.

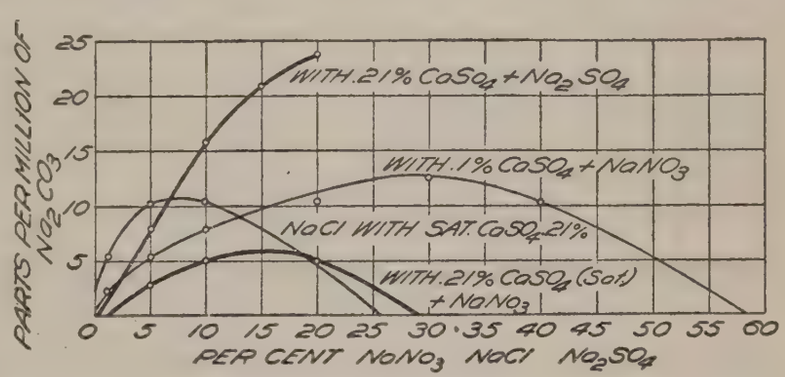
PARTS PER MILLION OF Na2CO3
25
20
15
10
5
0 5 10 15 20 25 30 35 40 45 50 55 60
PER CENT NaNO3 NaCl Na2SO4
WITH .21% CaSO4 + Na2SO4
WITH .1% CaSO4 + NaNO3
NaCl WITH SAT. CaSO4 .21%
WITH .21% CaSO4 (Soil) + NaNO3

FIG. 3.—Graphs showing the effect of gypsum on the formation of sodium carbonate in the reaction of calcium carbonate with sodium chlorid, sodium nitrate, or sodum sulphate.

TABLE VIII.—*Reaction between sodium nitrate and calcium carbonate in the presence of calcium sulphate*

Solution No.	Percentage of sodium nitrate.	Parts per million of sodium carbonate in the presence of—		Solution No.	Percentage of sodium nitrate.	Parts per million of sodium carbonate in the presence of—	
		0.1 per cent of calcium sulphate.	0.21 per cent of calcium sulphate.			0.1 per cent of calcium sulphate.	0.21 per cent of calcium sulphate.
1.....	0	0.0	0.0	5.....	20	10.6	5.3
2.....	1	2.6	.0	6.....	30	13.2	.....
3.....	5	5.3	2.6	7.....	40	10.6	0.0
4.....	10	7.9	5.3	8.....	60	0.0	0.0

TABLE IX.—*Reaction between sodium chlorid and calcium carbonate in 0.21 per cent solutions of calcium sulphate*

Solution No.	Percentage of sodium chlorid.	Parts per million of sodium carbonate formed.	Solution No.	Percentage of sodium chlorid.	Parts per million of sodium carbonate formed.
1.....	0	0.0	4.....	10	10.6
2.....	1	5.3	5.....	20	5.3
3.....	5	10.6	6.....	30	0.0

TABLE X.—*Reaction between sodium sulphate and calcium carbonate in 0.21 per cent solutions of calcium sulphate*

Solution No.	Percentage of sodium sulphate.	Parts per million of sodium carbonate formed.	Solution No.	Percentage of sodium sulphate.	Parts per million of sodium carbonate formed.
1	0	0.0	4	10	15.9
2	1	Trace.	5	15	21.2
3	5	7.9	6	20	23.8

In the case of all three salts, at some concentration there is an appreciable formation of sodium carbonate, although gypsum is present in an amount sufficient to saturate distilled water. This is more pronounced with sodium sulphate than with the other salts.

LIMITS OF THE FORMATION OF SODIUM CARBONATE IN PRESENCE OF SOLUBLE AND INSOLUBLE SALTS OF LIME

In titrating out the sodium carbonate formed by the action of the sodium salts on calcium carbonate it was noted that the color with phenolphthalein soon began to reappear in the solutions when calcium carbonate was present after the titration had been finished, indicating the formation of more sodium carbonate. Under field conditions the sodium carbonate formed would tend to be neutralized or "titrated out" by reacting with the organic matter or silicates of the soil.

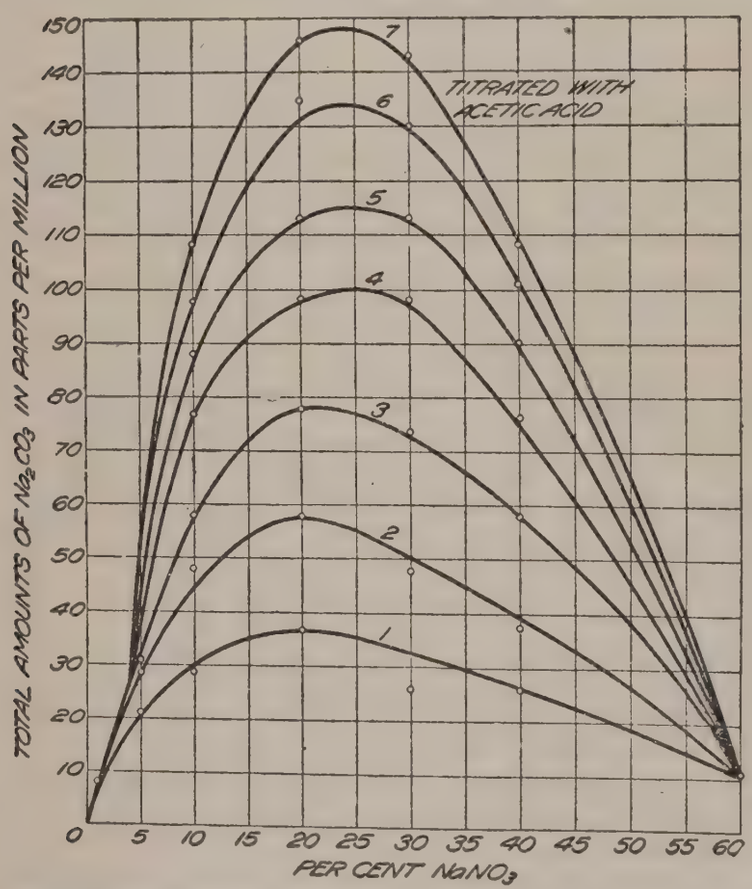

FIG. 4.—Graphs showing the sodium carbonate formed by reaction of calcium carbonate (solid phase present) with sodium nitrate. Sodium carbonate titrated out with acetic acid, allowing equilibrium to be established between successive titrations. Numbers refer to titrations. Each graph represents the total sodium carbonate neutralized up to and including that titration.

Acetic acid, representing a weak organic acid and one which gives a very soluble salt of lime, and oxalic acid, another weak acid which gives a very insoluble salt of lime, were taken in standard solutions and used instead of sulphuric acid to titrate out the sodium carbonate formed by the action of sodium nitrate and calcium carbonate. In a rough way

TABLE XI.—*Titrations with acetic acid of the sodium nitrate-calcium carbonate solution*

Solution No.	Strength of solution.	Parts per million of sodium carbonate (totals).						
		First titration.	Second titration.	Third titration.	Fourth titration.	Fifth titration.	Sixth titration.	Seventh titration.
1	Boiled water.....	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	1 per cent of sodium nitrate..	7.9	7.9	7.9	7.9	7.9	7.9	7.9
3	5 per cent of sodium nitrate..	21.2	29.1	29.1	34.4	34.4	34.4	34.4
4	10 per cent of sodium nitrate..	29.5	48.0	58.6	77.1	87.7	98.3	108.9
5	20 per cent of sodium nitrate..	37.1	58.3	79.5	98.0	113.9	135.1	145.7
6	30 per cent of sodium nitrate..	26.5	47.7	74.2	98.0	113.9	129.8	143.0
7	40 per cent of sodium nitrate..	26.5	37.1	58.3	76.8	90.0	103.2	108.5
8	60 per cent of sodium nitrate..	10.6	10.6	10.6	10.6	10.6	10.6	10.6

this was an imitation of the probable conditions existing in the field. When the color was titrated out of all the solutions, they were tightly stoppered and shaken until they had again reached equilibrium. This usually required about three days. The color was then titrated out a second time. This was repeated seven times. The results are shown in Tables XI and XII and figures 4 and 5.

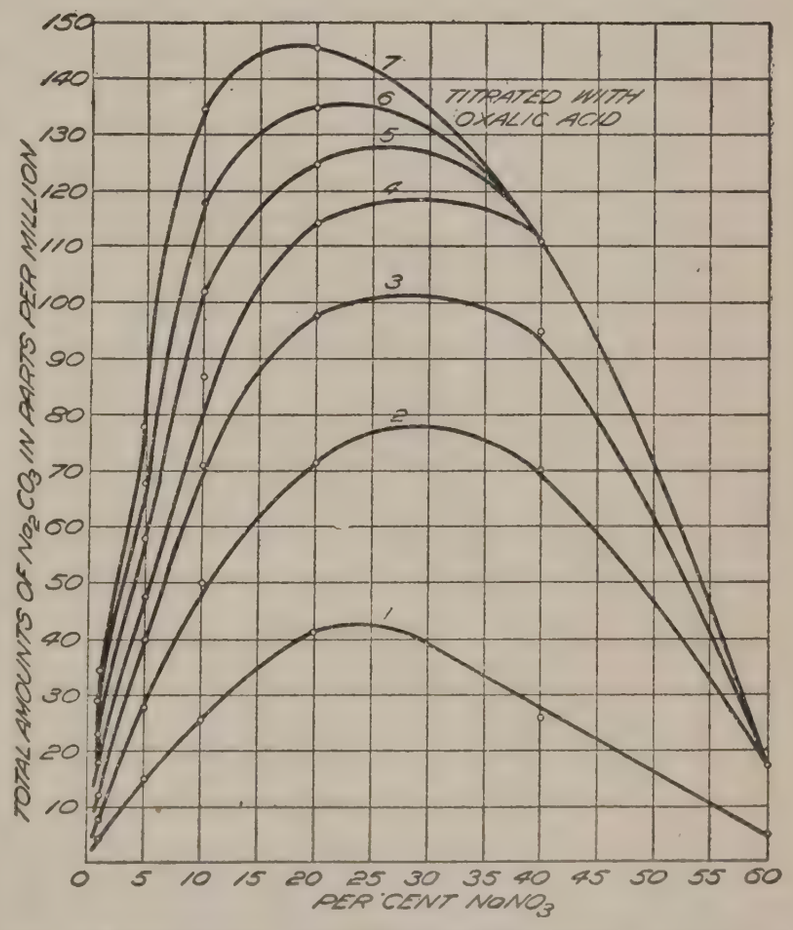

FIG. 5.—Graphs showing the sodium carbonate formed by reaction of calcium carbonate (solid phase present) with sodium nitrate. Sodium carbonate titrated out with oxalic acid, allowing equilibrium to be established between successive titrations. Numbers refer to titrations. Each graph represents the total sodium carbonate neutralized up to and including that titration.

In the reaction between sodium nitrate and calcium carbonate, sodium carbonate was formed, and this was titrated out by the acetic acid as represented by the following reaction: $Na_2CO_3+2HC_2H_3O_2 \rightleftarrows 2NaC_2H_3O_2+H_2O+CO_2$.

If under field conditions some sodium carbonate is formed by the action of sodium nitrate upon calcium carbonate and is neutralized by some weak soil acid, more sodium carbonate will be formed. This reaction will therefore continue until enough of the soluble lime salt, calcium nitrate, is formed to put an end to the reaction, as shown in Table V.

TABLE XII.—*Titrations with oxalic acid of the sodium nitrate-calcium carbonate solutions*

Solution No.	Strength of solution.	Parts per million of sodium carbonate (totals).						
		First titration.	Second titration.	Third titration.	Fourth titration.	Fifth titration.	Sixth titration.	Seventh titration.
1	Boiled water.....	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	1 per cent of sodium nitrate..	5.3	8.0	13.3	18.6	23.9	29.2	34.5
3	5 per cent of sodium nitrate..	15.9	29.1	39.7	47.6	58.2	68.8	79.4
4	10 per cent of sodium nitrate..	26.5	50.3	71.5	87.4	103.3	119.2	135.1
5	20 per cent of sodium nitrate..	42.4	71.6	98.1	114.0	124.6	135.2	145.8
7	40 per cent of sodium nitrate..	26.5	71.5	95.3	111.2	111.2	111.2	111.2
8	60 per cent of sodium nitrate..	5.3	18.5	18.5	18.5	18.5	18.5	18.5

The oxalic acid titration of the sodium carbonate formed in this reaction is represented as follows: $Na_2CO_3 + H_2C_2O_4 \rightleftarrows Na_2C_2O_4 + H_2O + CO_2$, or sodium carbonate and oxalic acid in equilibrium with sodium oxalate, water, and carbon dioxid. The sodium oxalate thus formed would react

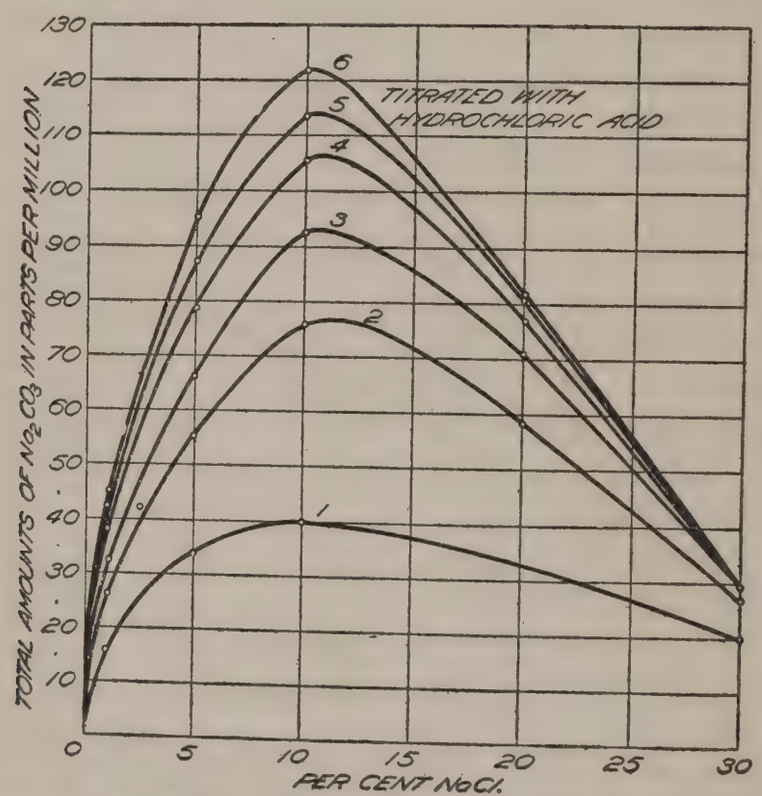

FIG. 6.—Graphs showing the sodium carbonate formed by reaction of calcium carbonate (solid phase present) and sodium chlorid. Sodium carbonate titrated out with hydrochloric acid, allowing equilibrium to be established between successive titrations. Numbers refer to titrations. Each graph represents the total sodium carbonate neutralized up to and including that titration.

with the soluble calcium nitrate produced by the first reaction and the insoluble calcium oxalate would be precipitated: $Na_2C_2O_4 + Ca(NO_3)_2 \rightleftarrows CaC_2O_4 + 2NaNO_3$.

A noticeable feature of these curves is their tendency to elongate in the meridian where the formation of sodium carbonate is most pro-

nounced. When oxalic acid is used, so that an insoluble salt of lime is formed, there is a pronounced tendency for the curves to swing toward the axis of ordinates.

The system, sodium nitrate-calcium carbonate, was then titrated out with nitric acid and the systems, sodium chlorid-calcium carbonate and

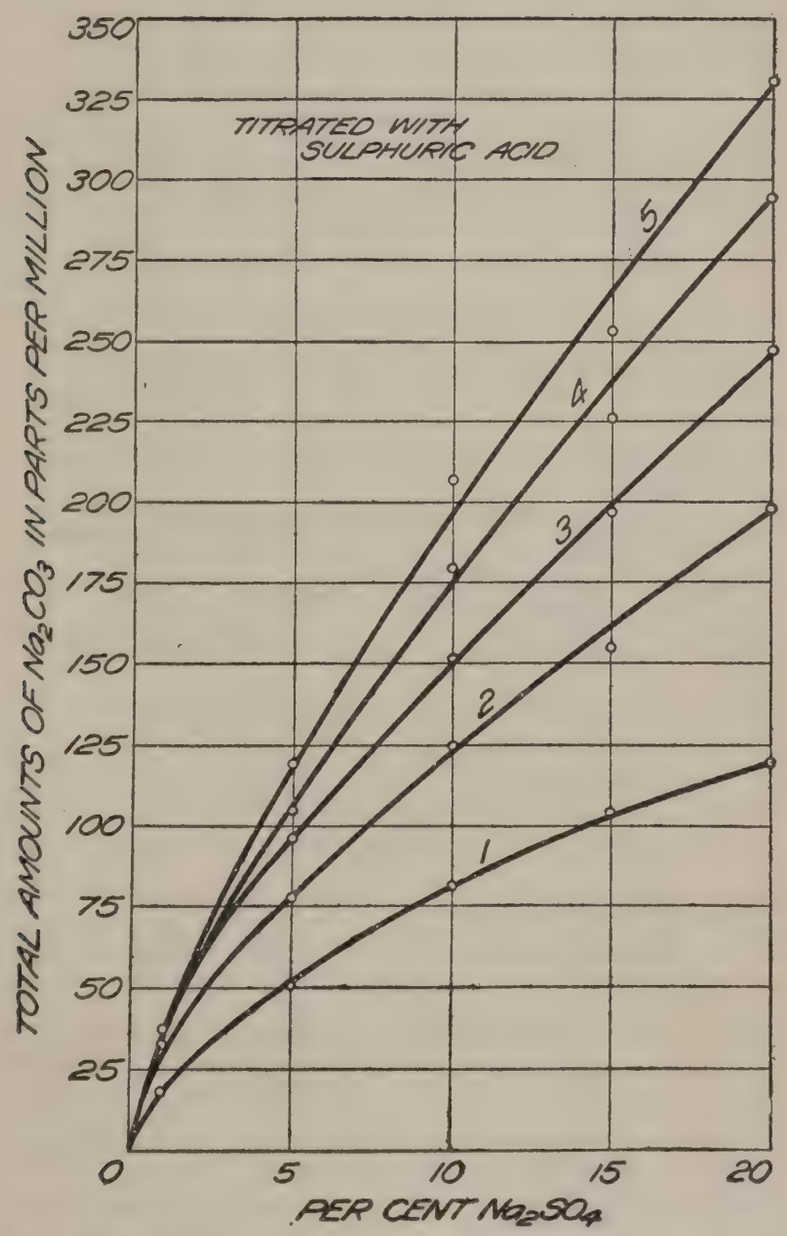

FIG. 7.—Graphs showing the sodium carbonate formed by reaction of calcium carbonate (solid phase present) and sodium sulphate. Sodium carbonate titrated out with sulphuric acid, allowing equilibrium to be established between successive titrations. Numbers refer to titrations. Each graph represents the total sodium carbonate neutralized up to and including that titration.

sodium sulphate-calcium carbonate, were titrated out in the same way with hydrochloric acid and sulphuric acid, respectively. These results are given in Tables XIII, XIV, and XV, and the curves for the hydrochloric and sulphuric acid titrations are shown on figures 6 and 7.

TABLE XIII.—*Titrations with nitric acid of the sodium nitrate-calcium carbonate solution*

Solution No.	Parts per million of sodium carbonate (totals).						
	Percentage of sodium nitrate.	1st titration.	2d titration.	3d titration.	4th titration.	5th titration.	6th titration.
1	0	0.0	0.0	0.0	0.0	0.0	0.0
2	1	10.6	23.8	31.7	37.0	44.9	52.8
3	5	39.7	94.1	92.6	105.8	118.0	128.6
4	10	66.2	111.3	132.5	145.7	158.9	165.8
5	20	60.9	94.9	121.4	137.3	145.1	153.0
6	30	34.4	68.8	84.7	95.3	103.9	106.5
7	40	34.4	58.2	74.1	79.4	79.4	79.4
8	60	23.8	37.0	37.0	37.0	37.0	37.0

TABLE XIV.—*Titrations with hydrochloric acid of the sodium chlorid-calcium carbonate solutions*

Solution No.	Parts per million of sodium carbonate (totals).						
	Percentage of sodium chlorid.	1st titration.	2d titration.	3d titration.	4th titration.	5th titration.	6th titration.
1	0	0.0	0.0	0.0	0.0	0.0	0.0
2	1	15.9	26.5	31.8	37.1	42.4	45.0
3	5	34.4	55.6	66.2	79.5	87.4	95.4
4	10	39.7	76.8	92.7	106.0	113.9	122.0
5	20	26.5	58.3	71.5	76.8	82.1	82.1
6	30	21.2	26.5	29.1	29.1	29.1	29.1

TABLE XV.—*Titrations with sulphuric acid of the sodium sulphate-calcium carbonate solutions*

Solution No.	Parts per million of sodium carbonate (totals).					
	Percentage of sodium sulphate.	1st titration.	2d titration.	3d titration.	4th titration.	5th titration.
1	0	0.0	0.0	0.0	0.0	0.0
2	1	21.2	34.4	37.0	37.0	37.0
3	5	53.0	76.8	95.3	108.5	121.7
4	10	79.5	124.5	153.6	182.7	209.2
5	15	106.0	156.3	195.7	224.8	251.6
6	20	122.0	198.8	249.1	294.1	336.5

In the soil, under field conditions, in the presence of carbon dioxid the greater part of the sodium carbonate would take up carbon dioxid and form sodium bicarbonate $Na_2CO_3 + CO_2 + H_2O \rightleftharpoons 2NaHCO_3$. The three systems described above were run, and carbon dioxid in solution was used

to titrate out the phenolphthalein color. A standard solution of carbon dioxid was prepared by saturating water containing calcium carbonate in

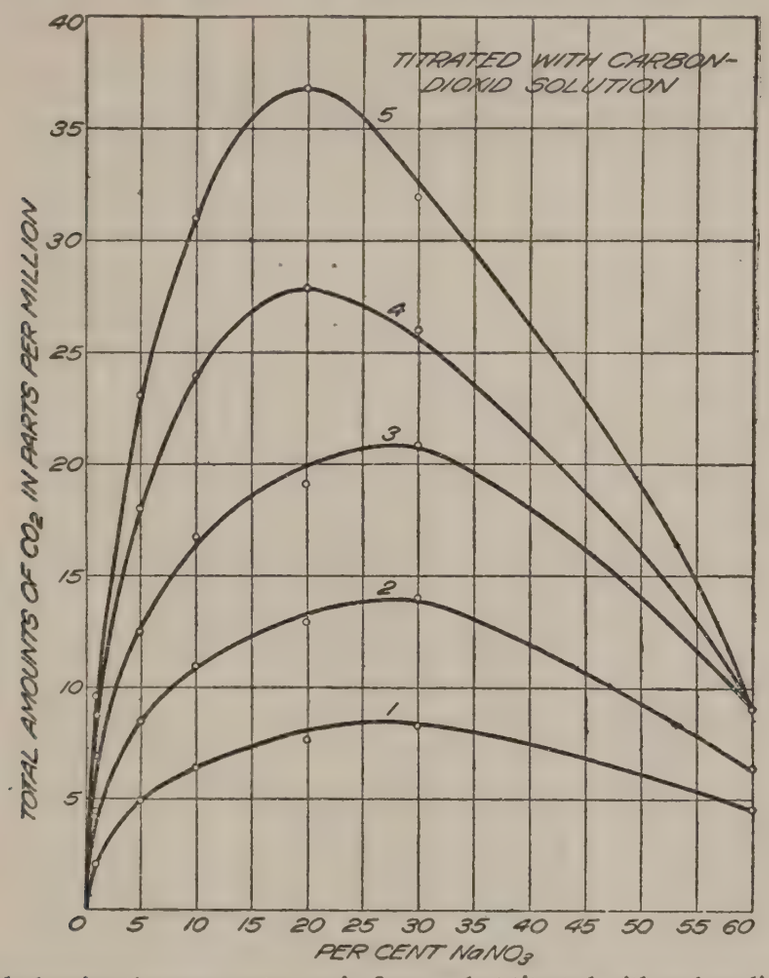
TITRATED WITH CARBON-DIOXID SOLUTION
TOTAL AMOUNTS OF CO_2 IN PARTS PER MILLION
PER CENT $NaNO_3$
0 5 10 15 20 25 30 35 40 45 50 55 60
5 10 15 20 25 30 35 40
1
2
3
4
5

FIG. 8.—Graph showing the same system as in figure 5, but titrated with carbon-dioxid solution.

excess with the carbon-dioxid gas. A fairly stable solution of calcium bicarbonate (or calcium carbonate dissolved in carbon dioxid) was ob-

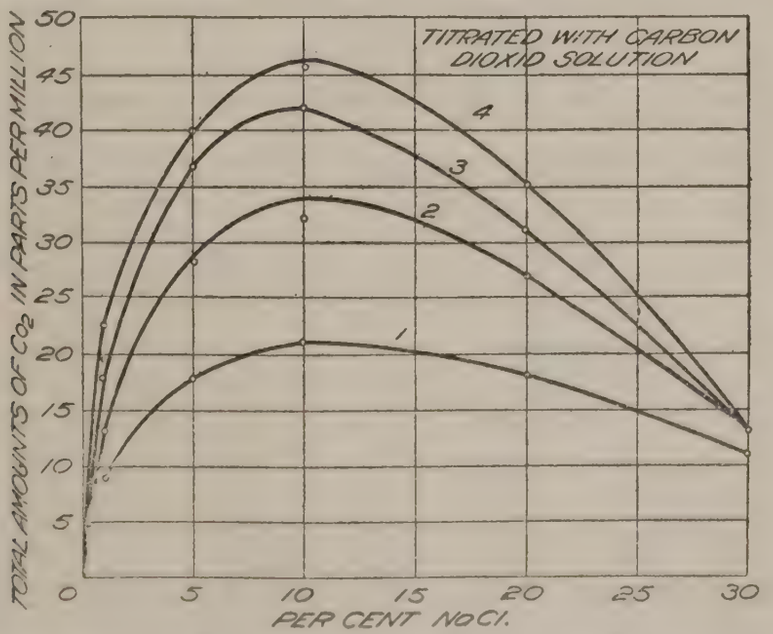
TITRATED WITH CARBON DIOXID SOLUTION
TOTAL AMOUNTS OF CO_2 IN PARTS PER MILLION
PER CENT NaCl.
0 5 10 15 20 25 30
5 10 15 20 25 30 35 40 45 50
1
2
3
4

FIG. 9.—Graph showing the same system as in figure 6, but titrated with carbon-dioxid solution.

tained and standardized to contain 360 parts per million of carbon dioxid. The results of these titrations are shown in Tables XVI, XVII,

and XVIII, and figures 8, 9, and 10. The titration of the control, in which no sodium salt was present, was subtracted from each of the others.

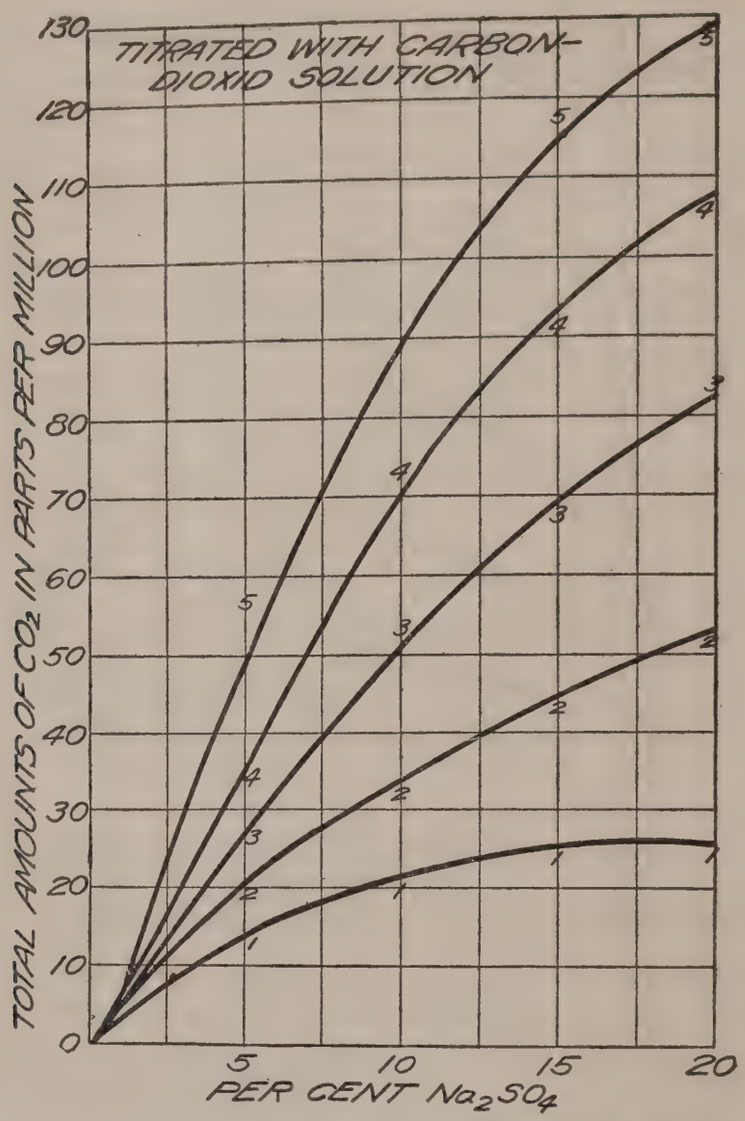

FIG. 10.—Graph showing the same system as in figure 7, but titrated with carbon-dioxid solution.

TABLE XVI.—*Titrations with carbon-dioxid solutions of the sodium nitrate-calcium carbonate solutions*

Solution No.	Parts per million of sodium carbonate (totals).					
	Percentage of sodium nitrate.	1st titration.	2d titration.	3d titration.	4th titration.	5th titration.
1	0	0.0	0.0	0.0	0.0	0.0
2	1	2.0	4.5	7.0	8.8	9.8
3	5	5.0	8.6	12.5	17.9	23.3
4	10	6.3	11.0	16.7	23.9	31.1
5	20	7.6	13.0	19.1	28.1	37.1
6	30	8.0	14.2	21.0	26.4	31.8
7	60	4.7	6.5	9.0	9.0	9.0

TABLE XVII.—*Titrations with carbon-dioxid solutions of the sodium chlorid calcium carbonate solutions*

Solution No.	Parts per million of carbon dioxid required (totals).				
	Percentage of sodium chlorid	1st titration.	2d titration.	3d titration.	4th titration.
1	0	0.0	0.0	0.0	0.0
2	1	9.0	14.4	18.7	22.3
3	5	18.0	28.8	36.7	40.3
4	10	21.6	32.4	42.1	46.1
5	20	18.0	27.0	31.3	35.3
6	30	10.8	12.6	12.6	12.6

TABLE XVIII.—*Titrations with carbon-dioxid solutions of the sodium sulphate calcium carbonate solutions*

Solution No.	Parts per million of carbon dioxid required (totals).					
	Percentage of sodium sulphate.	1st titration.	2d titration.	3d titration.	4th titration.	5th titration.
1	0	0.0	0.0	0.0	0.0	0.0
2	1	3.6	5.0	3.9	3.9	3.9
3	5	14.4	21.6	27.7	34.9	55.5
4	10	19.8	34.2	54.7	74.5	88.9
5	15	23.4	42.6	66.7	91.1	117.1
6	20	25.2	54.0	81.7	106.9	128.5

By considering the curves, one after another, a very definite idea is obtained of what might happen in the soil when a minimum amount of carbon dioxid is present and being generated continuously. The sodium salts, acting upon the calcium carbonate, would form a small amount of sodium carbonate, and this would combine with the carbon dioxid being generated in the soil and form sodium bicarbonate. Equilibrium would be upset and more sodium carbonate would be formed, which in its turn would be converted into sodium bicarbonate, and the reactions would continue until equilibrium was established. Equilibrium would depend upon the amount of the soluble lime salt formed in the reaction.

EQUILIBRIUM UNDER SOIL CONDITIONS

Cameron and Seidell, in studying the reaction of sodium chlorid and sodium sulphate with calcium carbonate, drew air through the solutions until equilibrium was established with atmospheric air. In applying their results to soil conditions one is apt to fall into error, for soil air contains a great deal more carbon dioxid than atmospheric air. Carbon dioxid will hold calcium carbonate in solution in a fairly stable form until an inert gas is bubbled through the solution. This bubbling process will effectually wash out the carbon dioxid and precipitate the salt. In the

the same way the equilibrium between carbonates and bicarbonates can be changed by modifying the partial pressure of the carbon dioxid in the gas phase. In a study of soil solutions a system whose stability is dependent upon the gas phase is often of more importance than one consisting wholly of stable salts. Equilibrium conditions are, furthermore, not necessarily reached in any soil solution. The movement of the soil moisture may remove the salt which is formed in one place and carry it to another in a rather unstable condition

The presence of the carbon dioxid in the atmospheric air is due in large part to the action of the bacteria and other organisms upon the organic matter of the soil. If a soil solution containing sodium chlorid, for example, be in contact with the solid calcium carbonate and the bacteria begin to generate carbon dioxid, the gas will appear and pass through the soil solution in its way through the soil toward the outside air. In other words, the equilibrium between sodium chlorid and calcium carbonate, so far as soil conditions are concerned, may be determined by a much higher partial pressure of carbon dioxid than is present in atmospheric air.

REACTION BETWEEN SODIUM SALTS AND CALCIUM CARBONATE IN PRESENCE OF CARBON DIOXID AT ATMOSPHERIC PRESSURE

Solutions of sodium salts with the solid calcium carbonate were prepared as before described and brought to equilibrium with carbon dioxid. This was accomplished by passing carbon dioxid into the solutions until the gas that was readily absorbed had been taken up. The shaker bottles (1-quart milk bottles), which were about half full of the solutions, were then filled with carbon dioxid, tightly stoppered, and shaken until final equilibrium was reached. This filling of the bottle with carbon dioxid and shaking it had to be repeated a great many times and over a period of several days. The final product represented equilibrium between the sodium salt and calcium carbonate in an atmosphere approaching pure carbon dioxid. Portions of the solution were withdrawn and titrations made with standard sulphuric acid. The titration figure of No. 1, in which

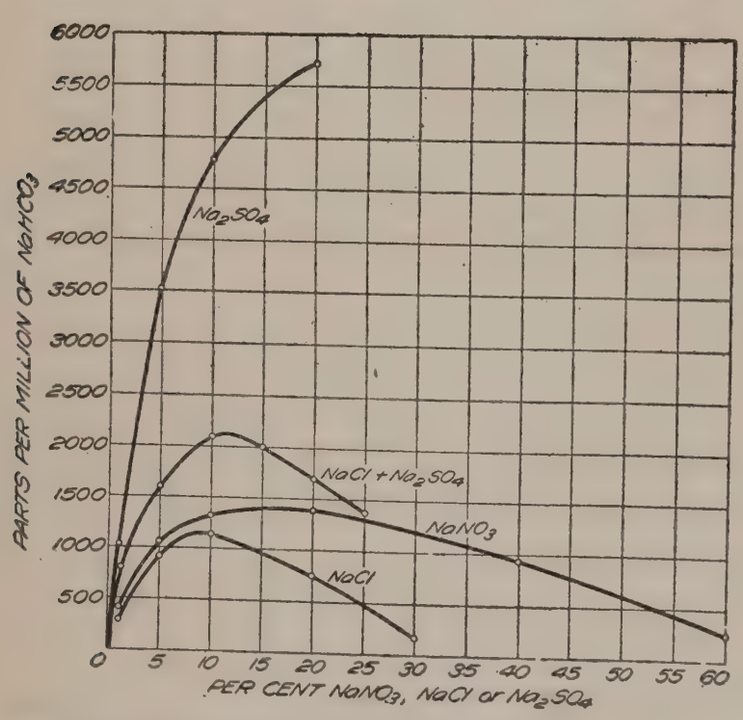

FIG. 11.—Graphs showing the concentration of sodium bicarbonate in the systems discussed above when in equilibrium with carbon dioxid at approximately atmospheric pressure.

there was no sodium salt, was subtracted from each of the other readings, and the results calculated to sodium bicarbonate. As methyl orange is not sensitive in a concentrated solution of some of the sodium salts, the titrations were made by adding an excess of the standard acid, boiling off the liberated carbon dioxid, and titrating back the excess with standard sodium hydrate, using phenolphthalein as an indicator. Tables XIX, XX, XXI, and XXII, and figure 11 show the amount of sodium bicarbonate formed in the presence of carbon dioxid.

After all the determinations had been made and duplicated, an excess of calcium sulphate was added to the solutions and they were again shaken until they had reached equilibrium. This action of the sodium salts upon calcium carbonate in the presence of gypsum is also shown in the above-mentioned tables and in figure 12.

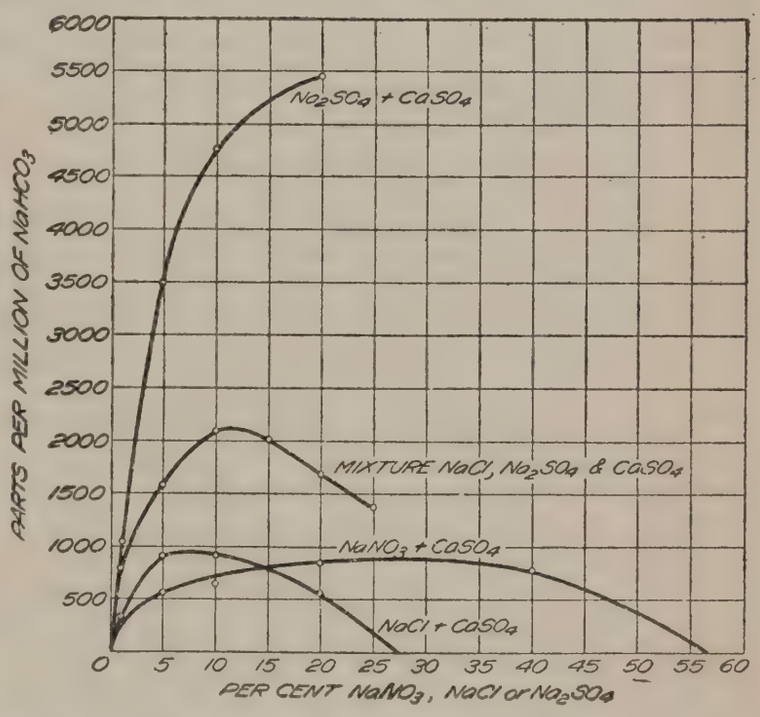

FIG. 12. Graph showing the same systems as in figure 11, with the addition of calcium sulphate in excess.

In short, a system consisting of calcium carbonate in excess carbon dioxid at atmospheric pressure, and one or more of the three salts sodium chlorid, sodium nitrate, or sodium sulphate, may react to form very appreciable quantities of sodium bicarbonate. The maximum amount of sodium bicarbonate formed in each system was as follows: With sodium nitrate, 1,386 parts per million; with sodium chlorid, 1,155 parts per million; with sodium sulphate, 5,712 parts per million; with equal parts of sodium chorid and sodium sulphate 2,100 parts per million.

TABLE XIX.—*Reaction between sodium nitrate and calcium carbonate in the presence of carbon dioxid*

Solution No.	Percentage of sodium nitrate.	Parts per million of sodium bicarbonate formed with—		Solution No.	Percentage of sodium nitrate.	Parts per million of sodium bicarbonate formed with—	
		Sodium nitrate.	Sodium nitrate+ calcium sulphate.			Sodium nitrate.	Sodium nitrate+ calcium sulphate.
1	0	0	0	5	20	1,386	840
2	1	462	336	6	40	966	798
3	5	1,050	546	7	60	252	0
4	10	1,302	672				

TABLE XX.—*Reaction between sodium chlorid and calcium carbonate in the presence of carbon dioxid*

Solution No.	Percentage of sodium chlorid.	Parts per million of sodium bicarbonate formed with—		Solution No.	Percentage of sodium chlorid.	Parts per million of sodium bicarbonate formed with—	
		Sodium chlorid.	Sodium chlorid + calcium sulphate.			Sodium chlorid.	Sodium chlorid + calcium sulphate.
1	0	0	0	4	10	1,155	924
2	1	357	353	5	20	735	546
3	5	987	924	6	30	147	0

TABLE XXI.—*Reaction between mixtures of equal parts of sodium chlorid and sodium sulphate, and calcium carbonate in the presence of carbon dioxid*

Solution No.	Percentage in mixture of sodium chlorid + sodium sulphate.	Parts per million sodium bicarbonate formed with equal parts of—		Solution No.	Percentage in mixture of sodium chlorid + sodium sulphate.	Parts per million sodium bicarbonate formed with equal parts of—	
		Sodium chlorid + sodium sulphate.	Sodium chlorid + sodium sulphate + calcium.			Sodium chlorid + sodium sulphate.	Sodium chlorid + sodium sulphate + calcium.
1	0	0	0	5	15	2,016	2,016
2	1	798	798	6	20	1,680	1,680
3	5	1,596	1,596	7	25	1,386	1,386
4	10	2,100	2,100				

TABLE XXII.—*Reaction between sodium sulphate and calcium carbonate in the presence of carbon dioxid*

Solution No.	Percentage of sodium sulphate.	Parts per million sodium bicarbonate formed with—		Solution No.	Percentage of sodium sulphate.	Parts per million sodium bicarbonate formed with—	
		Sodium sulphate alone.	Sodium sulphate + calcium sulphate.			Sodium sulphate alone.	Sodium sulphate + calcium sulphate.
1	0	0	0	4	10	4,788	4,788
2	1	1,008	1,008	5	20	5,712	5,712
3	5	3,528	3,528				

THEORETICAL EFFECT OF A FIELD APPLICATION OF GYPSUM ON BLACK ALKALI

It was long ago suggested by Dr. Hilgard that an application of gypsum would improve soils containing black alkali. This method of reclaiming alkali soils has been used a great many times, with and without success. By reference to the foregoing tables and graphs, one can form a definite idea of what will happen when gypsum is applied to any par-

ticular type of alkali. It will be noted that the presence of calcium sulphate materially affected the reaction in the case of sodium nitrate and sodium chlorid; but, as might be expected, no effect was in evidence in the case of sodium sulphate or the mixture containing sodium sulphate, since in the reaction of sodium sulphate and calcium carbonate gypsum (calcium sulphate) is one of the salts formed. Aside from the effect of lime in the rôle of an antagonistic agent, which will be discussed later, one would predict from these results that an application of gypsum would have little or no effect in overcoming black alkali that is being formed by the action of sodium sulphate or mixtures of alkali containing sodium sulphate upon lime. Furthermore, as many irrigation waters already contain gypsum in appreciable amounts, little or no beneficial effect may be expected from an application of gypsum to soils irrigated with such waters.

EFFECT OF SOLUBLE LIME SALTS UPON THE FORMATION OF SODIUM BICARBONATE

As has been pointed out before, equilibrium must not necessarily be reached in any of these reactions before the resulting components are

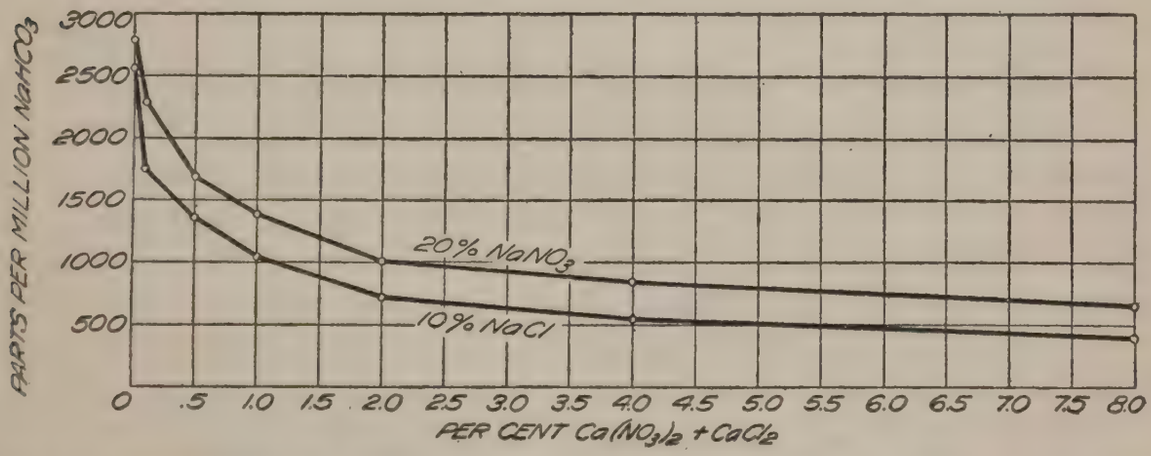

FIG. 13.—Graphs showing the effect of soluble calcium salts upon the formation of sodium bicarbonate.

carried away by drainage or the capillary action of the water. However, in case the soluble lime remained in the place where it was formed, the reaction would, of course, grow less with the increasing concentration of lime. In order to determine the effect of these soluble lime salts on the formation of sodium bicarbonate, solutions containing graduated amounts of calcium nitrate in 20 per cent solutions of sodium nitrate, and graduated amounts of calcium chlorid in 10 per cent solutions of sodium chlorid were prepared and brought to equilibrium by bubbling carbon-dioxid gas through them. These results are shown in Tables XXIII and XXIV and in figure 13.

TABLE XXIII.—*Reaction between 20 per cent solutions of sodium nitrate and calcium carbonate in the presence of calcium nitrate and carbon dioxid at atmospheric pressure*

Solution No.	Percentage of calcium nitrate.	Parts per million of sodium bicarbonate formed.	Solution No.	Percentage of calcium nitrate.	Parts per million of sodium bicarbonate formed.
1	0.0	2,814	5	2.0	1,008
2	.1	2,268	6	4.0	898
3	.5	1,680	7	8.0	672
4	1.0	1,428			

TABLE XXIV.—*Reaction between 10 per cent solutions of sodium chlorid and calcium carbonate in the presence of calcium chlorid and carbon dioxid at atmospheric pressure*

Solution No.	Percentage of calcium chlorid.	Parts per million of sodium bicarbonate formed.	Solution No.	Percentage of calcium chlorid.	Parts per million of sodium bicarbonate formed.
1	0.0	2,562	5	2.0	731
2	.1	1,764	6	4.0	563
3	.5	1,386	7	8.0	420
4	1.0	1,067			

Unquestionably a great part of the black alkali found in the arid and semiarid West is due to the action of the sodium salts on calcium carbonate in the presence of more or less carbon dioxid. Sodium bicarbonate is thus formed and carried to the surface as such and there, upon the evaporation of water, gives up part of its carbon dioxid and becomes the normal carbonate, or black alkali. The wet areas of the lowland, where black alkali is known to be more prevalent, lend themselves very well to its formation. Here we have water which is necessary for bacterial action and which tends to hold the carbon in solution and prevent its rapid escape into the atmosphere.

In the consideration of black alkali its formation under field conditions in a practically saturated solution of the sodium salt is not an overdrawn conception. When the sodium salt exists in any appreciable quantity in a soil it will at some time or other, by alternate dilution and evaporation, exist in all the different concentrations, from a dilute solution up to the salt crystal itself. This will happen in a soil that is irrigated regularly, saturated with water, and then allowed to dry down to near the wilting point between irrigations.

EXPERIMENTS WITH SAND AND SOIL

A large sample of soil was taken from the grounds of the new Citrus Experiment Station at Riverside, California, sifted through a 2 mm. sieve, mixed and dried in the sun for analysis. This soil, when shaken

up with distilled water and allowed to come to equilibrium, gave an extract that would show color with phenolphthalein upon boiling. This soil, however, would not visibly effervesce with dilute acid. It contained

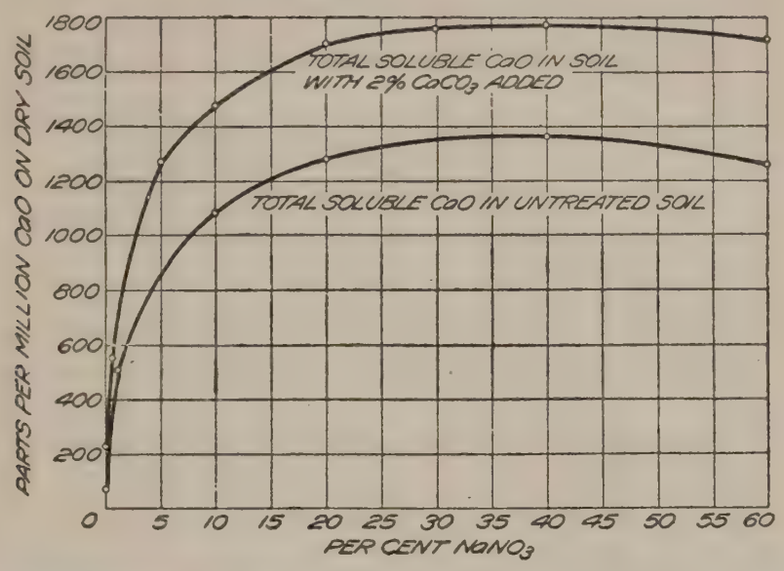

FIG. 14.—Graphs showing the effect of sodium nitrate on the solubility of calcium in soil.

just enough calcium carbonate or soluble silicates to make it basic in character. It contained 0.30 per cent of total calcium oxid on digestion with strong hydrochloric acid (specific gravity 1.115) and 0.83 per cent of humus. Part of the soil was taken and 2 per cent of its weight of

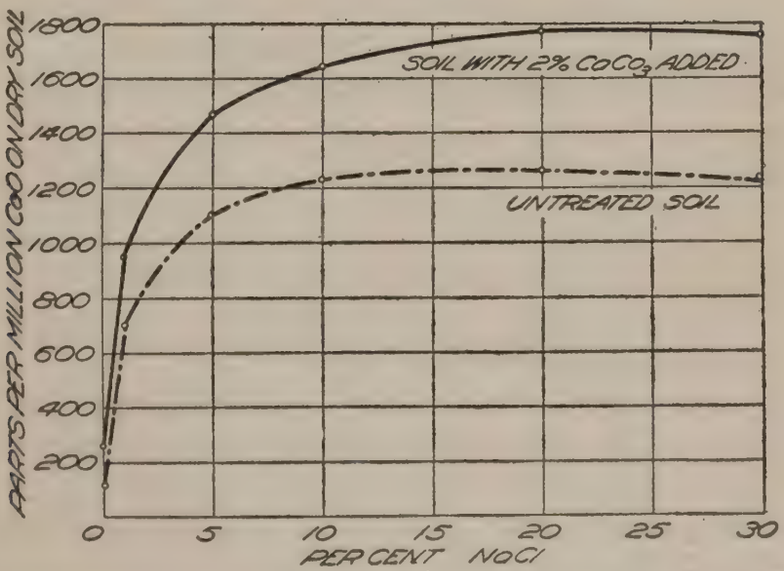

FIG. 15.—Graphs showing the effect of sodium chlorid on the solubility of calcium in soil.

calcium carbonate added and mixed with it. Portions of the original soil and also the soil to which the calcium carbonate had been added were shaken up with graduated solutions of each of the three salts sodium nitrate, sodium chlorid, and sodium sulphate and mixtures of

equal parts of sodium chlorid and sodium sulphate, in the proportion of 1 of soil to 5 of the solution and brought to equilibrium. The solutions were then filtered and analyzed for calcium oxid.

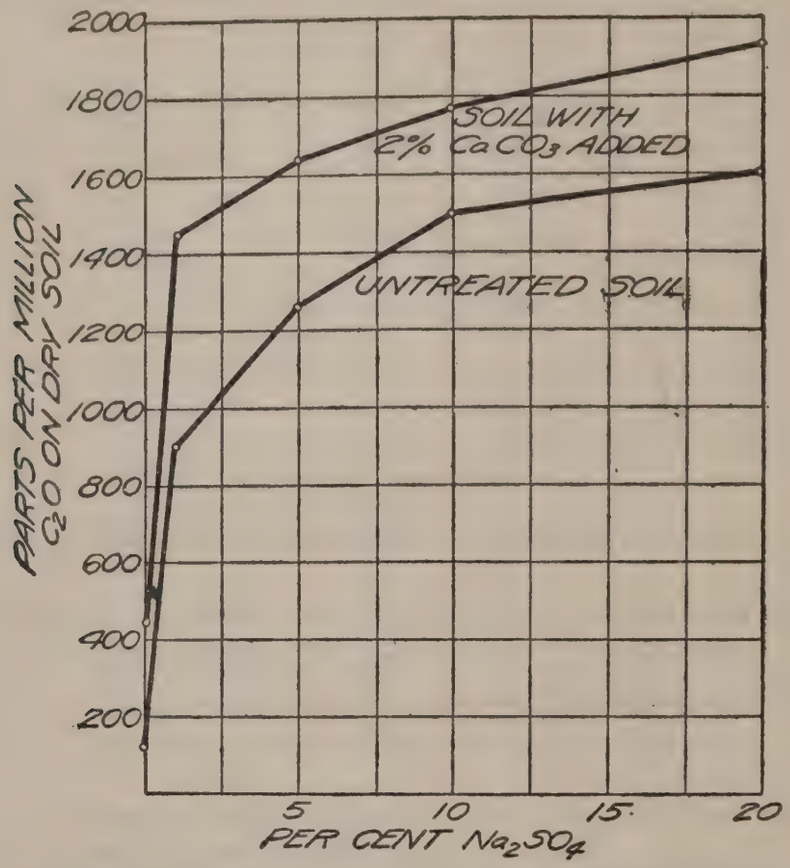

Fig. 16.—Graphs showing the effect of sodium sulphate on the solubility of calcium in soil.

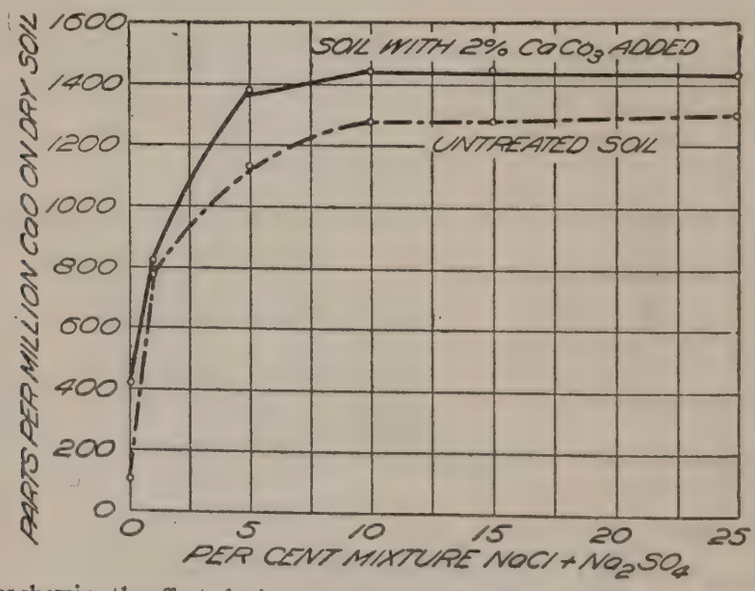

Fig. 17.—Graphs showing the effect of mixtures of sodium chlorid and sodium sulphate on the solubility of calcium in soil.

The amounts of lime, calculated to calcium oxid soluble in the different salts, are shown in Tables XXV, XXVI, XXVII, and XXVIII and are brought together in figures 14, 15, 16, and 17.

TABLE XXV.—*Solubility of lime in solutions of sodium nitrate*

Solution No.	Percentage of sodium nitrate.	Parts per million of soluble calcium oxid on basis of dry soil in—		Solution No.	Percentage of sodium nitrate.	Parts per million of soluble calcium oxid on basis of dry soil in—	
		Untreated soil.	Soil+2 per cent of calcium carbonate.			Untreated soil.	Soil+2 per cent of calcium carbonate.
1	0	70	230	5	20	1,280	1,708
2	1	533	558	6	30	.....	1,759
3	5	1,005	1,284	7	40	1,359	1,780
4	10	1,079	1,484	8	60	1,275	1,723

TABLE XXVI.—*Solubility of lime in solutions of sodium chlorid*

Solution No.	Percentage of sodium chlorid.	Parts per million of soluble calcium oxid on basis of dry soil in—		Solution No.	Percentage of sodium chlorid.	Parts per million of soluble calcium oxid on basis of dry soil in—	
		Untreated soil.	Soil+2 per cent of calcium carbonate.			Untreated soil.	Soil+2 per cent of calcium carbonate.
1	0	105	273	4	10	1,239	1,638
2	1	714	942	5	20	1,258	1,783
3	5	1,113	1,470	6	30	1,239	1,764

TABLE XXVII.—*Solubility of lime in solutions of sodium sulphate*

Solution No.	Percentage of sodium sulphate.	Parts per million of soluble calcium oxid on basis of dry soil in—		Solution No.	Percentage of sodium sulphate.	Parts per million of soluble calcium oxid on basis of dry soil in—	
		Untreated soil.	Soil+2 per cent of calcium carbonate.			Untreated soil.	Soil+2 per cent of calcium carbonate.
1	0	125	420	4	10	1,490	1,785
2	1	905	1,450	5	20	1,600	1,935
3	5	1,260	1,635				

TABLE XXVIII.—*Solubility of lime in solutions of mixtures of sodium chlorid and sodium sulphate*

Solution No.	Percentage of mixture (sodium chlorid+sodium sulphate).	Parts per million of soluble calcium oxid on basis of dry soil in—		Solution No.	Percentage of mixture (sodium chlorid+sodium sulphate).	Parts per million of soluble calcium oxid on basis of dry soil in—	
		Untreated soil.	Soil+2 per cent of calcium carbonate.			Untreated soil.	Soil+2 per cent of calcium carbonate.
1	0	125	420	4	10	1,278	1,438
2	1	780	815	5	15	1,285	1,445
3	5	1,155	1,395	6	25	1,300	1,430

REACTION BETWEEN SODIUM SALTS AND CALCIUM CARBONATE IN THE SOIL

By reference to the tables it will be noticed in every case that considerably more lime went into solutions in the soils to which calcium carbonate had been added than in the untreated soils. With the sodium nitrate, Table XXV, this difference amounted to 448 parts per million; with sodium chlorid, Table XXVI, to 525 parts per million; with sodium sulphate, Table XXVII, to 335 parts per million; and with a mixture of sodium chlorid and sodium sulphate, Table XXVIII, to 130 parts per million at the maximum concentration. The increase in the soluble lime can be accounted for by the action of the sodium salts upon calcium carbonate and the formation of the normal carbonate, or black alkali, and the subsequent formation of sodium bicarbonate—for example, $Na_2SO_4 + CaCO_3 \rightleftarrows Na_2CO_3 + CaSO_4$. With the development of car-

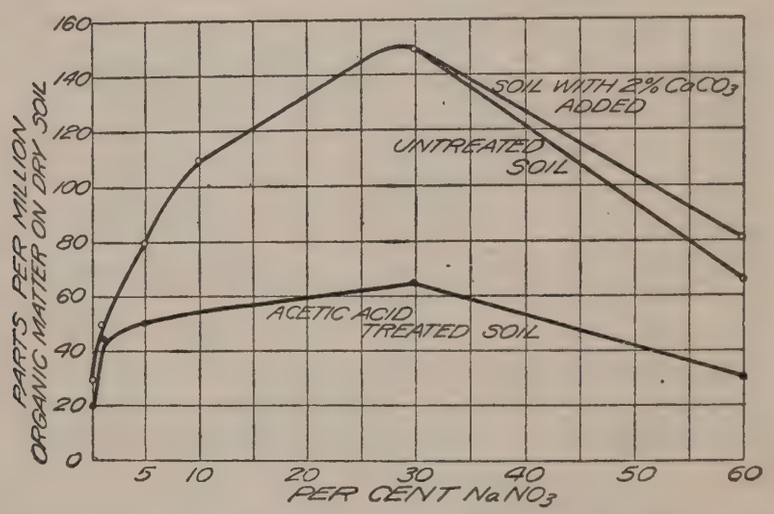

FIG. 18.—Graphs snowing the solubility of organic matter in soil in solutions of sodium nitrate.

bon dioxid in the solution the normal carbonate was converted into bicarbonate; however, at one time in the reaction, sodium carbonate existed, and when in this condition it was capable of reacting and did react upon the organic matter and the silica of the soil. It was noticed that the color of the solutions, owing to soluble organic matter, increased in intensity as the strength of the sodium salt increased, showing the action of the sodium carbonate formed in the reaction upon the organic matter.

ACTION OF SODIUM CARBONATE UPON ORGANIC MATTER IN THE SOIL

In order to have a soil which contained no carbonates, a quantity of the Station soil was mixed with dilute acetic acid until the soil extract was distinctly acid. This required about 4 c. c. of normal acetic acid to every 100 gm. of soil. After being thoroughly mixed, the soil was allowed to dry in the sun and the excess of acetic acid driven off in this way.

Portions of acid-treated soil, untreated soil, and soil to which 2 per cent of calcium carbonate had been added were then separately shaken up with the sodium salts in the usual way. When equilibrium was established, the solutions were filtered off and the soluble organic matter was determined by colorimeter readings against a known standard prepared from peat by extracting the organic matter with ammonia. These results are shown in Tables XXIX, XXX, XXXI, and XXXII and in figures 18, 19, 20, and 21.

TABLE XXIX.—*Solubility of organic matter in solutions of sodium nitrate*

Solution No.	Percentage of sodium nitrate.	Parts per million of soluble organic matter.			Solution No.	Percentage of sodium nitrate.	Parts per million of soluble organic matter.		
		Untreated soil.	Soil+2 per cent of calcium carbonate.	Acetic-acid-treated soil.			Untreated soil.	Soil+2 per cent of calcium carbonate.	Acetic-acid-treated soil.
1	0	30	30	20	4	10	110	110	55
2	1	50	50	45	5	30	150	150	65
3	5	80	80	50	6	60	65	80	30

TABLE XXX.—*Solubility of organic matter in solutions of sodium chlorid*

Solution No.	Percentage of sodium chlorid.	Parts per million of soluble organic matter.			Solution No.	Percentage of sodium chlorid.	Parts per million of soluble organic matter.		
		Untreated soil.	Soil+2 per cent of calcium carbonate.	Acetic-acid-treated soil.			Untreated soil.	Soil+2 per cent of calcium carbonate.	Acetic-acid-treated soil.
1	0	30	30	15	4	10	60	60	30
2	1	45	45	35	5	20	50	50	30
3	5	60	60	35	6	30	30	30	30

TABLE XXXI.—*Solubility of organic matter in solutions of sodium sulphate*

Solution No.	Percentage of sodium sulphate.	Parts per million of soluble organic matter.			Solution No.	Percentage of sodium sulphate.	Parts per million of soluble organic matter.		
		Untreated soil.	Soil+2 per cent of calcium carbonate.	Acetic-acid-treated soil.			Untreated soil.	Soil+2 per cent of calcium carbonate.	Acetic-acid-treated soil.
1	0	30	30	20	4	10	420	440	190
2	1	110	110	60	5	20	460	500	200
3	5	300	300	130					

TABLE XXXII.—*Solubility of organic matter in solutions of mixtures of sodium chlorid and sodium sulphate*

Solution No.	Percentage of mixture (sodium chlorid + sodium sulphate).	Parts per million of soluble organic matter.			Solution No.	Percentage of mixture (sodium chlorid + sodium sulphate).	Parts per million of soluble organic matter.		
		Untreated soil.	Soil + 2 per cent of calcium carbonate.	Acetic-acid-treated soil.			Untreated soil.	Soil + 2 per cent of calcium carbonate.	Acetic acid-treated soil.
1	0	30	30	15	4	10	190	190	90
2	1	75	75	45	5	15	190	190	.....
3	5	150	150	80	6	25	175	175	70

It will be seen by reference to the graphs that the curves for the untreated soil follow very closely the curves of the soil to which 2 per cent of calcium carbonate had been added. This seems to indicate that,

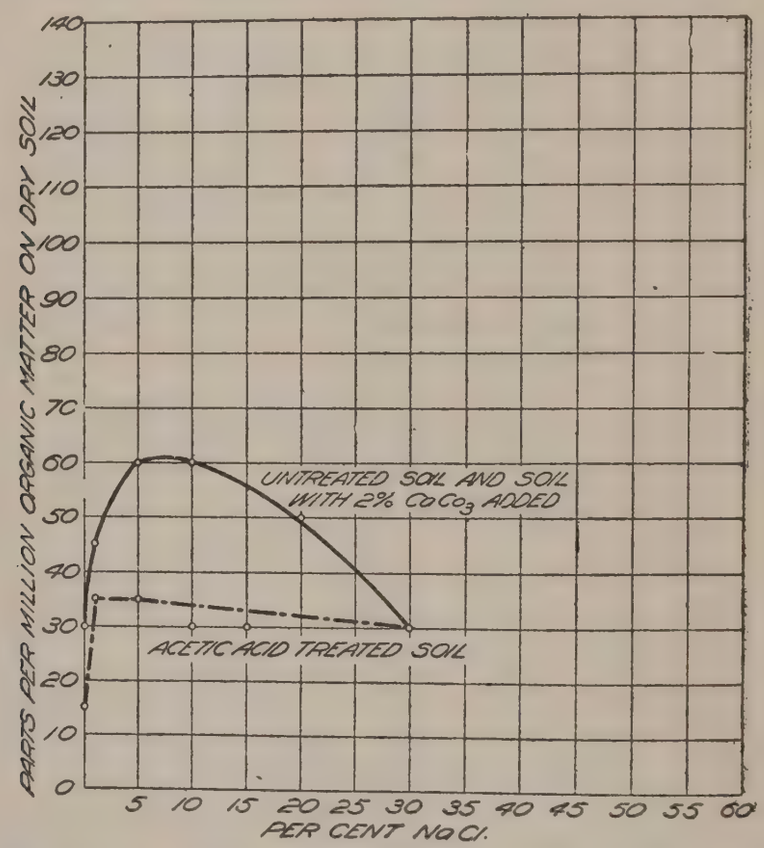

FIG. 19.—Graphs showing the solubility of organic matter in soil in solutions of sodium chlorid.

although there was not enough calcium carbonate in the untreated soil to visibly effervesce with acid, still there was enough to react with the sodium salts and to form sodium carbonate until equilibrium was reached, and to all purposes it was a calcareous soil. The difference in the solubility of the organic matter in the acid-treated soil and the lime or untreated soil is a fair measure of the action of the sodium salts upon calcium carbonate with the formation of sodium carbonate.

It seems from these results as if the normal carbonate was being formed, although it was impossible to detect it by phenolphthalein, except in one

instance, with the highest concentration of sodium sulphate. The sodium appeared, however, in the titrations as bicarbonate. The first chemical change seemed to be the formation of the normal carbonate,

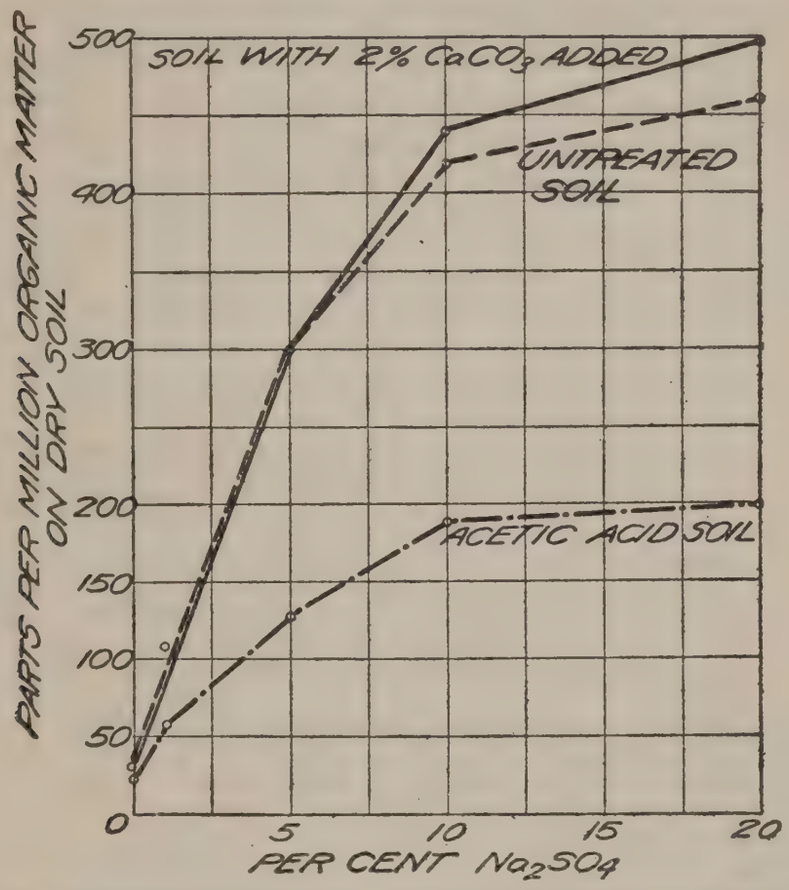

FIG. 20.—Graphs showing the solubility of organic matter in soil in solutions of sodium sulphate.

and while in this condition (the "nascent," or transition state, so to speak, between the carbonate and bicarbonate) it reacted with the organic matter and silica of the soil. Practically speaking, it was at

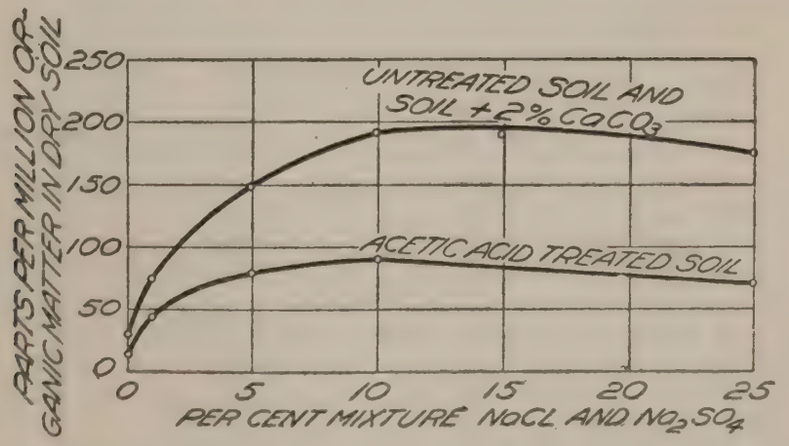

FIG. 21.—Graphs showing the solubility of organic matter in soil in presence of mixtures of sodium chlorid and sodium sulphate.

this stage in a "nascent" state, and seemed to possess some of the properties of a "nascent" element.

To test this point, a sample of soil was washed with dilute hydrochloric acid until the lime was all washed out. The soil was then washed

with water until free from hydrochloric acid, and was dried in the sun. Samples of the untreated, hydrochloric-acid-treated, and acetic-acid-treated soil were treated as outlined in the following tables. A saturated solution of calcium bicarbonate in solution with carbon dioxid was added to the soil at the rate of 0.4 per cent, on the basis of dry soil. An equivalent amount of calcium carbonate was added to another sample, and these were run with controls in comparison with other salts of calcium: (1) With no sodium salt present, (2) with 10 per cent of sodium nitrate, (3) with 10 per cent of sodium chlorid, and (4) with 10 per cent of sodium sulphate. These results are outlined in Tables XXXIII, XXXIV, XXXV, and XXXVI.

TABLE XXXIII.—*Solubility of organic matter and calcium carbonate, with no sodium salt added*

Solution No.	Treatment.	Parts per million of organic matter on dry soil.			Parts per million of calcium carbonate calculated from HCO_3.		
		Untreated.	Hydrochloric-acid treated.	Acetic-acid treated.	Untreated.	Hydrochloric-acid treated.	Acetic-acid treated.
1	Control	22	6	6	150	0	0
2	0.4 per cent calcium carbonate	22	22	16	500	350	575
3	0.4 per cent calcium carbonate as $Ca(HCO_3)_2$	18	6	6	3,500	3,200	3,125
4	10 per cent calcium nitrate	24	6	6	.....	.....	.....
5	10 per cent calcium chlorid	22	6	6	.....	.....	.....
6	Saturated calcium sulphate	18	6	6	.....	.....	.....

TABLE XXXIV.—*Solubility of organic matter and calcium carbonate in 10 per cent solutions of sodium nitrate*

Solution No.	Treatment.	Parts per million of organic matter on dry soil.			Parts per million of calcium carbonate calculated from HCO_3.		
		Untreated.	Hydrochloric-acid treated.	Acetic-acid treated.	Untreated.	Hydrochloric-acid treated.	Acetic-acid treated.
1	10 per cent sodium nitrate	52	6	12	75	0	0
2	10 per cent sodium nitrate +0.4 per cent of calcium carbonate	70	40	40	575	700	650
3	10 per cent sodium nitrate+0.4 per cent of calcium carbonate as $Ca(HCO_3)_2$	36	20	18	3,500	2,875	3,000

TABLE XXXV.—*Solubility of organic matter and calcium carbonate in 10 per cent solutions of sodium chlorid*

Solution No.	Treatment.	Parts per million of organic matter on dry soil.			Parts per million of calcium carbonate calculated from HCO_3.		
		Untreated.	Hydrochloric-acid treated.	Acetic-acid treated.	Untreated.	Hydrochloric-acid treated.	Acetic-acid treated.
1	10 per cent sodium chlorid.....	36	6	18	100	0	0
2	10 per cent sodium chlorid+0.4 per cent of calcium carbonate.....	40	36	30	850	500	600
3	10 per cent sodium chlorid+0.4 per cent of calcium carbonate as $Ca(HCO_3)_2$.....	24	20	18	3,625	2,875	3,000

TABLE XXXVI.—*Solubility of organic matter and calcium carbonate in 10 per cent solutions of sodium sulphate*

Solution No.	Treatment.	Parts per million of organic matter on dry soil.			Parts per million of calcium carbonate calculated from HCO_3.		
		Untreated.	Hydrochloric-acid treated.	Acetic-acid treated.	Untreated.	Hydrochloric-acid treated.	Acetic-acid treated.
1	10 per cent sodium sulphate+0.4 per cent of calcium carbonate.....	176	20	140	100	0	0
2	10 per cent sodium sulphate+0.4 per cent of calcium carbonate.....	208	120	250	1,000	875	1,125
3	10 per cent sodium sulphate+0.4 per cent of calcium carbonate as $Ca(HCO_3)_2$.....	104	40	150	3,250	2,625	2,875

As will be seen from Tables XXXIII to XXXVI, with the untreated soil little difference is shown, so far as the action on the organic matter is concerned, between calcium carbonate and other calcium salts when no sodium was added. With the hydrochloric-acid and acetic-acid-treated soils the amount of organic matter fell when the other salts of calcium were present, but rose to practically the same as the untreated soil when calcium carbonate was added. Calcium nitrate, calcium chlorid, and calcium sulphate do not alone seem to affect materially the solubility of the organic matter of the soil. The acid condition of the soil,

brought about by hydrochloric and acetic acids, decidedly decreased the solubility of the organic matter.

With solutions of sodium nitrate, sodium chlorid, and sodium sulphate the solubility of the organic matter is decidedly increased by the presence of calcium carbonate. The sodium salts, however, as shown in other work, have a solvent effect upon the organic matter aside from their action upon the calcium carbonate. This is particularly true of sodium sulphate.

The tables bring out one thing quite forcibly—the probable reaction of the sodium salts with calcium carbonate in the presence of the soil with the formation of normal sodium carbonate. In the cases where the lime was added as a bicarbonate, little or no reaction was noticed above the controls. In fact, the presence of calcium bicarbonate, as shown by experiments not included in this paper, tends to protect the organic matter rather than to bring it into solution. The action of the sodium salt on the calcium bicarbonate would result in the formation of sodium bicarbonate, which is much less active in the decomposition of organic matter. This will be brought out later.

The methyl-orange titration or the titration for bicarbonates (HCO_3) was made and for convenience calculated to calcium carbonate. This is also shown in the tables. The figures represent the amount of calcium carbonate that was brought into solution in the different treatments. In the case of calcium bicarbonate the figures remain fairly constant throughout the series. With the calcium carbonate, however, a distinct increase was noticed when the sodium salts were introduced, indicating to what extent the calcium carbonate had reacted with the sodium salts, with the formation of sodium carbonate.

ACTION OF CALCIUM CARBONATE UPON ORGANIC MATTER IN THE SOIL

There is a belief prevalent in some sections that calcium acts as a protective agent upon the organic matter of the soil. This is probably due to the repeated statement of Dr. Hilgard (6, p. 283, 380–381) that lime carbonate is the principal factor in the formation of humus. Lyon and Fippin (7, p. 127) state that—

> The loss of humus by leaching from soils rich in lime is very much less than in those soils poor in lime.

This is probably true, but the comparisons were no doubt made between a fertile limestone soil and a low-lying swamp or acid peat bog, and not between a limestone soil and an acid upland soil, in which the presence of a real acid is questionable, or an upland soil deficient in lime. It is unquestionably true that lime will precipitate many organic compounds, but it is yet to be shown that a given amount of humus will be retained in the soil longer in the presence of lime than in

the absence of it. It is the writer's opinion that calcium carbonate in itself has a tendency to bring the organic matter of the soil into solution, and this action is hastened by the presence of all the sodium salts. It is true that our limestone soils are our most fertile soils, and certainly contain the most organic matter, but this is probably brought about by the fact that the vast majority of humus-forming plants thrive best upon limestone soils. An upland acid soil usually supports but a sparse vegetation, and consequently accumulates little humus. The limestone or calcium carbonate unquestionably stimulates the activity of the bacterial flora, and in this way, if in no other, would tend to destroy the organic matter of the soil. The calcareous soils, then, probably are richer in humus, not because of the protective action of lime, but because of the greater supply of organic material.

When the Citrus soils of southern California are given plenty of water, the percentage of organic matter is without doubt a great factor in productivity. These soils are usually extremely low in organic matter, and a little variation one way or the other, brought about by proper or improper cultural methods, sometimes shows very striking results.

A series of pots were filled with the soil from the new Citrus station site and treated as follows:

1. Soil untreated.
2. Soil treated with 2 per cent of calcium carbonate.
3. Soil treated with 1 per cent of manure.
4. Soil treated with 1 per cent of manure +2 per cent of calcium carbonate.
5. Soil treated with 1 per cent of ground alfalfa.
6. Soil treated with 1 per cent of ground alfalfa+2 per cent of calcium carbonate.
7. Soil treated with 1 per cent of ground melilotus.
8. Soil treated with 1 per cent of ground melilotus+2 per cent of calcium carbonate.
9. Soil treated with 1 per cent of peat (leaf mold).
10. Soil treated with 1 per cent of peat +2 per cent of calcium carbonate.

Five other soils were collected from Corona and treated with 1 per cent of alfalfa, with and without lime. All of these pots were kept moist and allowed to stand approximately for one year before being planted to lemon seedlings. In every case a depressing effect was noticed when lime was added to the soil. Four representative 5-month-old plants are shown in Plate 62, A.

The effect of lime is not noticeable when the seedlings are planted immediately after the treatment and grown for several months. As organic matter is, under the conditions of culture, the controlling factor, it seems highly probable that the depressing action of lime upon the seedlings is due to its indirect action upon the organic matter of the soil. Even in the control soil, to which no organic matter was added, the lime seems to have attacked the little organic matter existing there and, in the common term, "burned it out."

The soil from the new Citrus station has been cultivated very little and therefore retains much of its original organic matter. It is higher in that respect than the average of the soils from the much cultivated Citrus groves in the vicinity. When planted to Citrus seedlings in pots it produced much better plants than the neighboring soils, at least during the period that these plants have been under observation. This is quite likely due to the higher percentage of active organic matter in the soil and would tend to explain the fact that young Citrus groves when planted on virgin soil usually grow well at first and show little mottling until they have reached an age of 8 years or more. By this time under the system of intensive cultivation now in common practice, the active organic matter is necessarily reduced to a minimum.

Four samples of hydrochloric-acid-treated soil were washed and placed in pieces of apparatus resembling lantern chimneys, and set in shallow reservoirs. They were given the treatments outlined in Table XXXVII. Distilled water and 20 per cent solutions of sodium nitrate were placed in the reservoirs beneath and allowed to pass up through the soil and evaporate on the surface. After four days the surface crust was scraped off and the amount of organic matter brought into solution was determined.

TABLE XXXVII.—*Solubility of organic matter of black alkali soil treated with sodium-nitrate solutions*

Solution No.	Soil treatment.	Solution used in reservoirs.	Parts per million of water-soluble organic matter on dry crust.
1	2 per cent of calcium carbonate.	Distilled water.....	0
2	None.....	20 per cent of sodium nitrate..	116
3	.....do.....	20 per cent of sodium nitrate with excess calcium carbonate.	150
4	2 per cent of calcium carbonate.	20 per cent of sodium nitrate..	690

1. Under the conditions of this experiment, when the soil contained calcium carbonate and was treated with distilled water, little or no organic matter was brought into solution.

2. When the soil contained no carbonates and was treated with a sodium-nitrate solution, a moderate amount of organic matter was dissolved, representing the solubility of the organic matter of the soil in sodium nitrate.

3. When sodium nitrate and calcium carbonate were brought together in the reservoir, the reaction with the formation of sodium carbonate took

place outside the soil. The sodium carbonate was changed into sodium bicarbonate, and the action of the bicarbonate upon the organic matter of the soil was only a little more than that of sodium nitrate alone.

4. When calcium carbonate was mixed with the soil and the sodium-nitrate solution introduced into it, the reaction which involved the formation of the sodium carbonate took place in contact with the soil. The action of the sodium carbonate upon the organic matter is clearly brought out.

Another sample of acetic-acid-treated soil was taken, treated, first with sodium sulphate, second with sodium sulphate and calcium carbonate, and third with sodium sulphate and calcium carbonate and then the solution saturated with carbon-dioxid gas. These were shaken until equilibrium was established. Determinations were then made of the soluble organic matter (Table XXXVIII).

TABLE XXXVIII.—*Solubility of the organic matter in acetic-acid-treated soil with the addition of salts*

Solution No.	Treatment.	Parts per million of soluble organic matter.
1	Acetic-acid-treated soil+10 per cent of sodium sulphate	120
2	Acetic-acid-treated soil+10 per cent of sodium sulphate+0.4 per cent of calcium carbonate	200
3	Acetic-acid-treated soil+10 per cent of sodium sulphate+0.4 per cent of calcium carbonate saturated with carbon-dioxid gas at atmospheric pressure	60

The fact that the presence of calcium carbonate increases the solubility of the organic matter indicates that the sodium sulphate is acting upon calcium carbonate with the formation of the normal sodium carbonate, and this is acting upon the organic matter of the soil. When carbon dioxid is present in excess, the reaction forms sodium bicarbonate, which shows little action upon organic matter. This experiment was repeated with sodium chlorid, with practically the same results.

ACTION OF SODIUM CARBONATE AND SODIUM BICARBONATE UPON ORGANIC MATTER

Having demonstrated the fact that in the soil sodium salts react with lime to form sodium carbonate and this attacks the organic matter of the soil, the pure salts sodium carbonate and sodium bicarbonate were added in varying concentrations to the station soil and brought to equilibrium. Portions of the solutions were withdrawn and titrated for carbonates and bicarbonates, and determinations were made of the

soluble organic matter. These are shown in Tables XXXIX and XL, and in figure 22.

The difference between the amount of sodium carbonate added to the solution and that shown by the titration after equilibrium has been established is indicated in the column "Lost" in Table XXXIX. By subtracting the control, No. 1, fron the others and dividing the sodium carbonate "lost" into the parts per million of organic matter brought into solution, the parts per million of organic matter brought into solution for every 100 parts per million of sodium carbonate lost are obtained. This shows the relative solvent action of sodium carbonate when acting in weak and in fairly strong solutions. Contrary to what one might expect, this experiment seems to show that a unit of sodium carbonate is nearly 10 times more effective in a strong concentration than in a weak one. It is well known, however, that, when sodium carbonate is added to the soil, a part of it becomes fixed—that is, it is absorbed by the soil grains or is combined with the silicates or other like bodies of the soil. This fixation would remove in absolute amounts almost as much from a weak solution as from a moderately strong one, and would, of course, leave relatively less free sodium carbonate in the weak solution than in the strong one to act upon the organic matter. The carbon dioxid existing in the soil would also convert a small amount of sodium carbonate into sodium bicarbonate. This action would be almost equal in the weak and the strong solutions. The sodium bicarbonate thus formed would be almost negligible, so far as its action upon the organic matter is concerned.

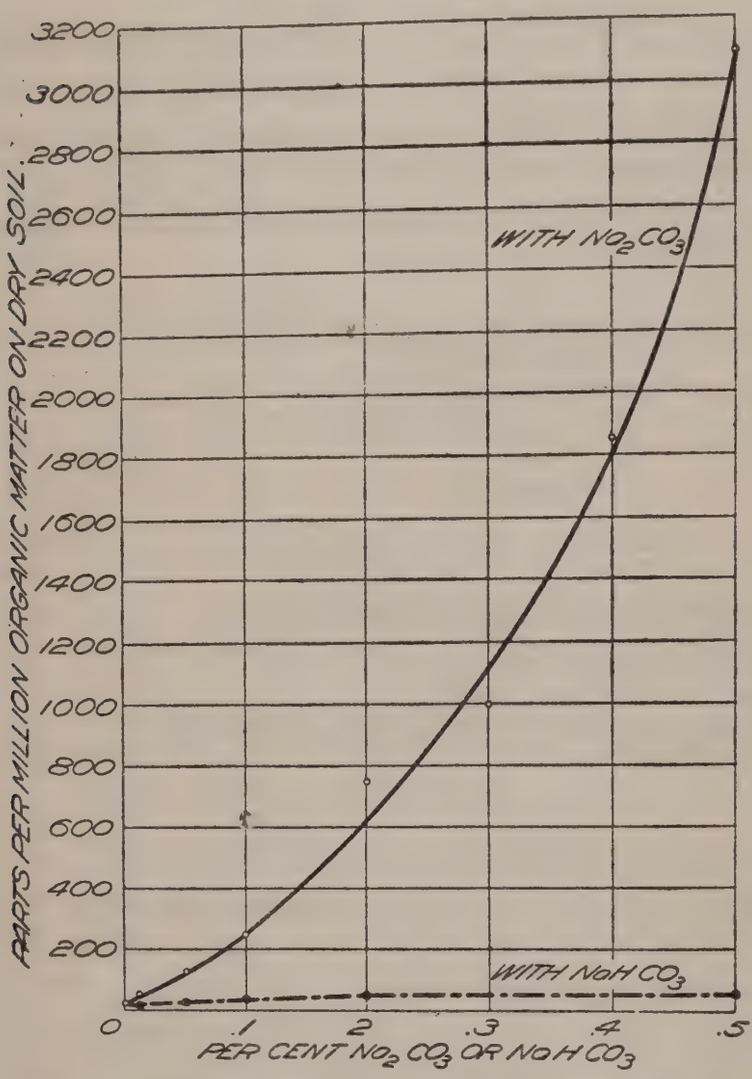

FIG. 22.—Graphs showing the solubility of organic matter in a soil in sodium-carbonate and sodium-bicarbonate solutions.

TABLE XXXIX.—*Solubility of organic matter in sodium-carbonate solutions*

Solution No.	Percentage of sodium carbonate.			Parts per million of organic matter on soil.	Parts per million after subtracting No. 1 (control) from others.	Parts per million of organic matter brought into solution for every 100 parts per million of sodium carbonate lost.
	Added.	Recovered.	Lost.			
1	0.0	0.0	0.0	30	0	0
2	.01	Trace.	.01	60	30	30
3	.05	.019	.031	130	100	32
4	.10	.051	.049	250	220	45
5	.20	.117	.083	750	720	87
6	.30	.212	.088	1,000	970	110
7	.40	.297	.103	1,875	1,854	179
8	.50	.390	.110	3,100	3,070	279

TABLE XL.—*Solubility of organic matter in sodium bicarbonate*

Solution No.	Percentage of sodium bicarbonate.		Parts per million of organic matter on soil.	Parts per million after subtracting No. 1 (control) from others.
	Added.	Recovered.		
1	0.00	0.005	24	0
2	.01	.015	24	0
3	.05	.059	30	6
4	.10	.105	44	20
5	.20	.193	60	36
6	.50	.445	70	46

As the soils contain some bicarbonates, more was recovered in some cases than was added. Sodium bicarbonate seemed to exert little effect upon the organic matter of the soil.

EFFECT OF SODIUM SALTS UPON THE SOLUBILITY OF CALCIUM CARBONATE IN SOILS

In treating a soil with a sodium-chlorid solution, with and without calcium carbonate, and analyzing it for lime in the usual way, a striking phenomenon is to be noticed. In Table XLI is shown the total amount of water-soluble lime calculated to calcium carbonate obtained by two different methods of analysis. In the first method the total lime was precipitated as calcium oxalate and weighed as calcium oxid. In the second method the bicarbonates in the solution were titrated with standard acid and the titrations calculated to calcium carbonate.

TABLE XLI.—*Solubility of calcium carbonate in soils*

Solution No.	Percentage of sodium chlorid.	Total water-soluble calcium oxid.			HCO_3 titrations.		
		Soil control.	Soil+2 per cent calcium carbonate.	Difference.	Soil control.	Soil+2 per cent calcium carbonate.	Difference.
1	0	105	273	168	150	450	300
2	1	714	942	228	75	525	450
3	5	1,113	1,470	357	50	525	475
4	10	1,239	1,638	399	0	425	425
5	20	1,258	1,783	525	0	250	250
6	30	1,239	1,764	525	0	75	75

By subtracting the water-soluble lime extracted from the controls from the lime recovered from soil to which calcium carbonate had been added, a difference is obtained, representing the effect of the application of calcium carbonate. In the same way are subtracted the bicarbonate determinations and a difference secured, also representing the effect of the calcium carbonate. It will be seen that there is a regular increase in the case of the total water-soluble lime, and, first a rise, then a drop, in the case of the bicarbonates. The calcium carbonate has gone into solution but is not present as a carbonate or bicarbonate. The presence of sodium chlorid in the higher concentrations seems to be forcing back the solubility of calcium as a bicarbonate. This is also true with sodium nitrate and sodium sulphate.

ALKALI CRUSTS IN IRRIGATED REGIONS

In many of the irrigated districts in southern California, especially around Riverside and Corona, the so-called crusts or efflorescence of alkali salts is frequently noticed on the surface of the soil. These crusts appear after each irrigation as a light, fluffy, brown efflorescence, particularly along the edge of the irrigation furrow. They are not crusts, except in the popular conception of the term, in that they do not harden the surface of the soil; they are also to be distinguished from the black, gummy crust formed by black alkali, and from the crystalline crust of the other sodium salts constituting white alkali.

They are usually dissolved by each irrigation and carried down into the soil only to be returned to the surface in a few days by the upward movement and evaporation of the water. This upward and downward movement is continued throughout the season until the crusts are finally dissolved by the winter rains and carried down to some depth into the soil or off by drainage. Unless the winter rains are unusually heavy, the crusts usually appear again in the spring after the first irrigation. Both the crusts themselves and their water extracts are extremely toxic to Citrus seedlings, the toxicity being entirely out of proportion to the known toxicity of the inorganic salts that make up the solution.

Four samples of these crusts were collected by scraping the surface soil, and extracts were made by shaking them with distilled water and filtering off the soil through Pasteur filters. These solutions were then evaporated to dryness, the residue was dried at 100° F., and portions were taken for analysis. These analyses are given in Table XLII expressed as ions, and also empirically combined as salts, on the basis of the dry water-soluble material.

TABLE XLII.—*Percentage composition of water-soluble material*

GROVE A, RIVERSIDE.				HIGHGROVE GROVE.			
Ions.		Combined as salts.		Ions.		Combined as salts.	
Constituent.	Per cent.	Constituent.	Percent.	Constituent.	Per cent.	Constituent.	Per cent.
Ca	9.36	$CaSO_4$	17.80	Ca	11.82	$CaSO_4$	18.38
Mg	1.52	$Ca(NO_3)_2$	16.95	Mg	2.47	$Ca(NO_3)_2$	26.05
Na	5.01	$MgCl_2$	1.55	K	1.70	$Mg(NO_3)_2$	15.01
K	7.09	$Mg(NO_3)_2$	7.35	Na	7.98	KCl	3.16
SO_4	12.58	KCl	8.00	SO_4	13.03	$NaNO_3$	9.34
NO_3	19.02	$KHCO_3$	3.40	Cl	5.98	NaCl	7.45
Cl	4.99	K_2CO_3	2.42	NO_3	39.30	$NaHCO_3$	3.66
CO_3	1.79	Na_2CO_3	1.33	HCO_3	2.66	Na	1.50
HCO_3	2.04	Na	4.58			Organic matter	15.06
		Organic matter	36.70				
CORONA GROVE.				GROVE B, RIVERSIDE.			
Ca	13.11	$CaSO_4$	13.13	Ca	14.72	$CaSO_4$	5.72
Mg	1.70	$Ca(NO_3)_2$	37.88	Mg	2.14	$Ca(NO_3)_2$	53.51
K	2.32	$Mg(NO_3)_2$	5.75	K	1.41	$Mg(NO_3)_2$	13.02
Na	6.22	$MgCl_2$	3.01	Na	3.76	KCl	2.70
SO_4	9.30	KCl	4.43	SO_4	4.04	$NaNO_3$	.04
Cl	9.15	NaCl	7.93	NO_3	51.45	NaCl	2.83
NO_3	33.38	Na_2CO_3	1.46	Cl	3.00	Na_2CO_3	.43
CO_3	.83	$NaHCO_3$	1.54	CO_3	.17	$NaHCO_3$	1.06
HCO_3	1.12	Na	2.04	HCO_3	.77	Na	2.21
		Organic matter	22.93			Organic matter	18.50

When the bases are combined with the acids, beginning with calcium, and following with magnesium, potassium, and sodium in order, it will be noticed that there is some sodium left over uncombined. This probably existed in part in combination with the organic acids, which were not determined. The sodium no doubt at one time existed as sodium carbonate and had attacked the organic matter of the soil; therefore, at the time of the analysis, it was partly locked up in organic combination. A high percentage of soluble organic matter was to be expected. A high percentage of calcium nitrate is also noticeable. This is due to the fact that active nitrification had been going on in the soil with the formation of nitric acid, which had combined with the calcium carbonate of the soil, with the formation of calcium nitrate. Theoretically these crusts could not form in a soil containing no carbonates.

Several samples of soil were taken from lemon groves, good and poor, without and with the alkali crust. These soils were placed in 6-inch pots and planted with very young lemon seedlings. In every case the soils from the good groves gave good plants, while the soils from the poor groves, the groves which had the alkali crust, gave poor plants. Two representative plants are shown in Plate 62, B. Both of these soils were taken from the feeding zone (second foot); the poor one, therefore contained little of the alkali crust which was, at the time of sampling, principally on the surface, but certainly enough to affect the lemon seedlings. The analysis of the crust appearing on the surface of this soil is given in Table XLII, Corona grove.

The high percentage of soluble organic matter was the most striking feature of the analysis of the water-soluble salts, constituting the crusts. This amounted to as high as 36 per cent of the dry material and was sufficient to give color to all the solutions, ranging from brown to nearly black. It will be shown later that, with the exception of sodium carbonate, none of the salts likely to occur has an appreciable effect in bringing the organic matter of the soil into solution. In fact, most of the lime salts seem either to be inert in this respect or else to exert a protective action upon the organic matter. The action of sodium carbonate upon organic matter is pronounced.

None of the crusts would react with phenolphthalein; neither did their solutions give any reaction for sodium carbonate, until they had been boiled for some time. This showed that no sodium carbonate was present at the time of sampling, but the color of the solution indicated, if it did not prove, that sodium carbonate had at one time been present.

ORIGIN OF BARREN, OR "SLICK," SPOTS

The fact that a very toxic compound is formed by the union of sodium carbonate and organic matter goes far to explain many of the phenomena noticed in the field. At North Platte, Nebr., in the river valley, there are many barren spots in the grain and alfalfa fields that are probably due to this cause. These spots are usually absolutely barren, and are surrounded by luxuriant growths of grain or alfalfa. By the casual observer these are attributed to excessive amounts of sodium sulphate or sodium chlorid, but a chemical examination of the soils showed little difference in the inorganic salt content of the good and poor spots. These spots are typical of a thousand that are scattered over the arid and semi-arid regions of the West. The predominating alkali at North Platte is sodium sulphate. The soil is rich in calcium carbonate and humus, and the conditions are ideal for the reaction before described. When extracts from the good and poor spots from this vicinity are made, the poor spots can be readily detected by the deep color of the solutions, owing to the organic matter, and by a characteristic "soapy," or alkali, odor.

In a recent bulletin of the Utah Experiment Station (4) an attempt was made to determine the amount of alkali necessary to prohibit the growth of certain field crops. Some barren spots, like those described at North Platte, were selected and comparisons made between these spots and good places in the same or adjoining fields, and the assumption was made that the barrenness of the poor spots was due to the common "alkali" salts. In the light of the results here presented, the present writer seems justified in suggesting the possibility that conditions other than alkali might enter into the barrenness of these spots.

The difference in the solubility of the salts formed in the reactions between the sodium salts and calcium carbonate, and the difference in their rate of movement through the soil is responsible in a large measure for the accumulation of the different salts on the surface in different places. We may have "black alkali" spots, in which sodium carbonate predominates, or the so-called "slick spots," in which calcium carbonate predominates, or the so-called "niter spots," in which calcium nitrate predominates.

The presence of black alkali, or sodium carbonate, in such small amounts as 0.1 to 0.05 per cent renders some soils unfit for cultivation. The injurious effects on field crops, generally attributed to sodium carbonate, is, as has been shown, often out of proportion to what might be expected from results obtained from studies in pure solutions. In the presence of the organic matter and silica of the soil the sodium carbonate is likely to enter into combination not only with the organic matter but with the silica of the soil, as fast as it is formed. In such cases its very presence is often overlooked, existing, as it does, in such small amounts. Enough carbon dioxid is usually added with the distilled water used in making the soil extract for analysis to convert the sodium carbonate to bicarbonate. It thus fails to show color with phenolphthalein, and the soil is said to contain no sodium carbonate. It does exist, however, in what might be termed a transition state between its formation and its combination with the silica or organic matter.

In its action upon the finely divided material of the soil the characteristic puddling or cementing is likely to take place. This action usually occurs in spots and is not often extended over wide continuous areas. Many of the barren spots in the semiarid areas are probably due not to the accumulation of alkali, but to the cementing action of sodium carbonate. The soil puddles, will not take water, and thereby soon becomes barren, the barrenness being due primarily to lack of water. Some excellent work has been done by Headley, Curtis, and Scofield (5) at Fallon, Nev., along this line.

In the humid regions the accumulation of injurious compounds in the soil is not a question of much importance. This is being taken care of by the rains, which make the movement of the soil water downward through the subsoil. The injurious bodies are then leached out. In the

arid and semiarid regions, however, with slight rainfall, under conditions of irrigation, little or no drainage can take place. The injurious compounds are then likely to accumulate in the soil. It seems to the writer that the accumulation of such combination of salts and organic matter as are here described should be dreaded. Such formations as these might well be considered the secondary stage of alkali accumulation, described in the first part of this paper.

It is an old adage in greenhouse work, "Water the pots until the water runs out of the bottom." In other words, to get the best results a little drainage is always necessary. In irrigation agriculture, however, when there is a scarcity of water, enough is not usually applied to cause any drainage, even when there is a porous soil with sandy or open subsoil. Under these conditions, if the winter rains are not heavy enough to produce the desired effect, the injurious products of decomposition are likely to accumulate year after year until they reach an amount that will seriously interfere with agriculture.

It seems to be a fact that good Citrus crops usually follow heavy winter rains. The rejuvenation, or "coming back," of many orchards may well be attributed to this. This was particularly noticeable in the Riverside area in the season of 1916 after the unusually heavy rains of the preceding winter. The groves probably did not "come back" on account of any change in the cultural treatment, as was thought by many, but on account of the removal of injurious compounds from the soil.

PROTECTIVE ACTION OF SODIUM CHLORID AND SODIUM SULPHATE UPON THE ORGANIC MATTER OF THE SOIL IN PRESENCE OF SODIUM CARBONATE

It has already been shown that sodium chlorid and sodium sulphate both have a slight solvent action upon the organic matter of the soil. This is especially true of sodium sulphate. In the presence of sodium carbonate, however, a remarkable phenomenon is to be observed. Both salts tend to reduce the solvent action of sodium carbonate.

The solvent action of sodium carbonate, which is far greater than that of the other sodium salts, is due in all probability to the ionized OH radical. Sodium carbonate being a strong base combined with a weak acid has a decided tendency to hydrolyze—that is, to combine with water in the following manner: $Na_2CO_3 + H_2O \rightleftarrows 2NaOH + H_2CO_3$. The sodium hydrate formed in this reaction will in turn ionize into Na and OH. The sodium hydrate formed by the hydrolysis, then, is directly responsible for its caustic action upon the organic matter of the soil, and its degree of ionization is a measure of it.

By introducing a salt with a common ion into a weak solution of sodium carbonate the ionization may be so forced back as no longer to show color with phenolphthalein. The sodium carbonate as such will still remain in solution, but will not be hydrolyzed. In this way sodium

chlorid, sodium sulphate, and sodium nitrate may under field conditions exert a protective action upon the organic matter of the soil from the solvent action of "black alkali."

A 0.5 per cent solution of sodium carbonate was prepared and used to make up soil extracts in the regular proportion of 1 of soil to 5 of solution. Graduated amounts of sodium chlorid and sodium sulphate were added to the solutions, which were brought to equilibrium. The amount of organic matter which went into solution in each instance is indicated in Tables XLIII and XLIV, and in figure 23.

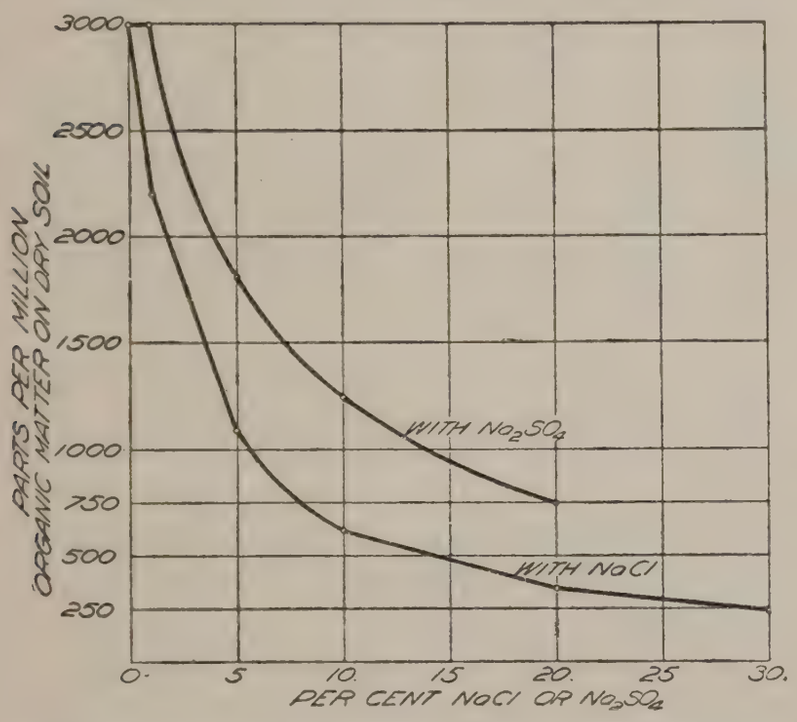

FIG. 23.—Graphs showing the protective action of sodium chlorid and sodium sulphate upon organic matter of the soil in the presence of sodium carbonate.

A rapid decrease is noticed in the amount of organic matter dissolved by 0.5 per cent of sodium carbonate when either of the other sodium salts are introduced into the solution. This action is more marked with sodium chlorid than with sodium sulphate. The neutral salts seem to be acting in a protective rôle upon the organic matter of the soil.

TABLE XLIII.—*Solubility of organic matter in sodium carbonate in the presence of sodium chlorid*

Solution No.	Percentage of sodium carbonate.	Percentage of sodium chlorid.	Parts per million of organic matter on dry soil.	Solution No.	Percentage of sodium carbonate.	Percentage of sodium chlorid.	Parts per million of organic matter on dry soil.
1.....	0.5	0	3,000	4.....	0.5	10	625
2.....	.5	1	2,200	5.....	.5	20	350
3.....	.5	5	1,100	6.....	.5	30	250

TABLE XLIV.—*Solubility of organic matter in sodium carbonate in the presence of sodium sulphate*

Solution No.	Percentage of sodium carbonate.	Percentage of sodium sulphate.	Parts per million of organic matter on dry soil.	Solution No.	Percentage of sodium carbonate.	Percentage of sodium sulphate.	Parts per million of organic matter on dry soil.
1.....	0.5	0	3,000	4.....	0.5	10	1,250
2.....	.5	1	3,000	5.....	.5	20	750
3.....	.5	5	1,800				

In Table XLV is shown the effect of sodium carbonate upon the organic matter of the soil, acting, first alone in amounts from 0 to 1 per cent, second in a 10 per cent solution of sodium chlorid, and third in a 10 per cent solution of sodium sulphate.

TABLE XLV.—*Solubility of organic matter in sodium carbonate in the presence of 10 per cent solutions of sodium chlorid and sodium sulphate*

Solution No.	Percentage of sodium carbonate.	Parts per million of organic matter.			Solution No.	Percentage of sodium carbonate.	Parts per million of organic matter.		
		Sodium carbonate alone.	Sodium carbonate + 10 per cent sodium chlorid.	Sodium carbonate + 10 per cent sodium sulphate.			Sodium carbonate alone.	Sodium carbonate + 10 per cent sodium chlorid.	Sodium carbonate + 10 per cent sodium sulphate.
1.....	0.0	30	60	420	4.....	0.50	3,000	650	1,500
2.....	.1	400	240	800	5.....	.75	3,700	800	1,800
3.....	.25	800	500	1,000	6.....	1.00	5,250	1,000	2,500

The same phenomenon is noticed as was shown in the preceding experiment; the destructive action of sodium carbonate is checked by the presence of the other sodium salts.

In Table XLVI and figure 24 is shown to what extent the reaction of sodium carbonate upon organic matter is reversible. Solutions of soil

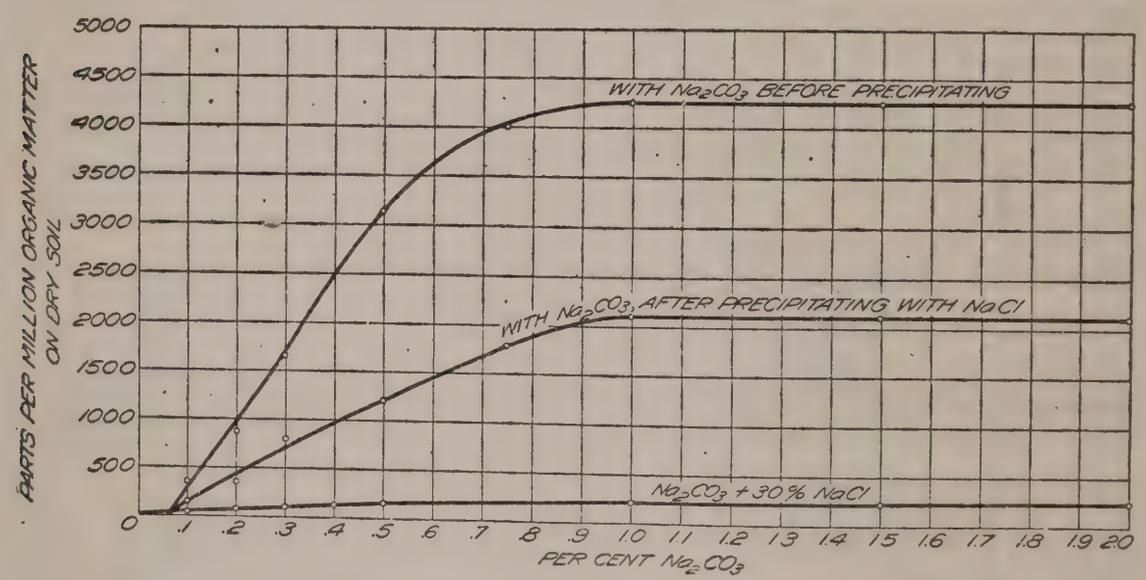

FIG. 24.—Graphs showing the organic matter dissolved from soil by sodium carbonate and afterwards precipitated by sodium chlorid.

were made with varying concentrations of sodium carbonate and the soil filtered off. Determinations of the organic matter were then made upon the solutions. An excess of sodium chlorid was then added to each of the solutions, the solution boiled, and the resulting precipitate filtered off. Determinations of the organic matter were again made on the filtrates. These final readings represented the amount of organic matter that went into solution with sodium carbonate, but which could not be precipitated out with sodium chlorid.

The solubility of organic matter in varying amounts of sodium carbonate when sodium chlorid was in the solution is also given.

TABLE XLVI.—*Solubility of organic matter in sodium-carbonate solutions*

Solution No.	Percentage of sodium carbonate added.	Parts per million organic matter on dry soil.			Solution No.	Percentage of sodium carbonate added.	Parts per million organic matter on dry soil.		
		Before precipitating with sodium chlorid.	After precipitating with sodium chlorid.	Solubility in sodium carbonate in presence of 30 per cent of sodium chlorid.			Before precipitating with sodium chlorid.	After precipitating with sodium chlorid.	Solubility in sodium carbonate in presence of 30 per cent of sodium chlorid.
1.....	0.1	360	140	40	5.....	.75	4,000	1,800	.....
2.....	.2	875	350	80	6.....	1.00	4,250	2,100	200
3.....	.3	1,650	800	100	7.....	1.50	4,250	2,100	220
4.....	.5	3,125	1,200	160	8.....	2.00	4,250	2,100	240

From the above table it will be noted that after the organic matter of the soil has once been brought into solution by the sodium carbonate, approximately one-half can be reprecipitated with sodium chlorid.

From all the results so far obtained it would seem that the injurious effect of sodium carbonate in its action upon the organic matter of the soil rests in that portion of the salt which is hydrolyzed into sodium hydrate. The rate of hydrolysis of sodium carbonate in pure solution and in the presence of sodium salts may be measured by means of the saponification of ethyl acetate. Ten c. c. of ethyl acetate were therefore put into 150 c. c. of 0.4 per cent of sodium carbonate, using pure water and increasing amounts of sodium chlorid. After standing with frequent shaking, for 20 minutes, a portion of the solution was withdrawn and titrated against standard acid, using phenolphthalein as an indicator. This titration was repeated after 40, 60, and 100 minutes, respectively. The amount of unsaponified sodium carbonate was thus determined, and by subtracting this from the total amount in the original solution, the quantity of saponified sodium carbonate was determined. This experiment was repeated with sodium sulphate, using a 0.49 per cent sodium carbonate. The results are shown in Tables XLVII and XLVIII and in figures 25 and 26.

TABLE XLVII.—*Saponification of ethyl acetate by sodium carbonate in the presence of sodium chlorid*

Solution No.	Per centage of sodium chlorid.	Percentage of sodium carbonate saponified in—				Solution No.	Per centage of sodium chlorid.	Percentage of sodium carbonate saponified in—			
		20 minutes.	40 minutes.	60 minutes.	100 minutes.			20 minutes.	40 minutes.	60 minutes.	100 minutes.
1.....	0	0.220	0.294	0.315	0.347	4.....	20	0.093	0.114	0.125	0.163
2.....	5	.190	.209	.230	.269	5.....	30	.061	.071	.082	.125
3.....	10	.135	.167	.188	.230						

TABLE XLVIII.—*Saponification of ethyl acetate by sodium carbonate in the presence of sodium sulphate*

Solution No.	Percentage of sodium sulphate.	Percentage of sodium carbonate saponified in—			
		20 minutes.	40 minutes.	60 minutes.	100 minutes.
1	0	0.318	0.392	0.428	0.445
2	10	.212	.275	.297	.318
3	20	.159	.212	.233	.254

These two tables clearly show to what degree the presence of sodium chlorid and sodium sulphate holds back the hydrolysis of sodium carbonate. Under field conditions we might expect black alkali to be more

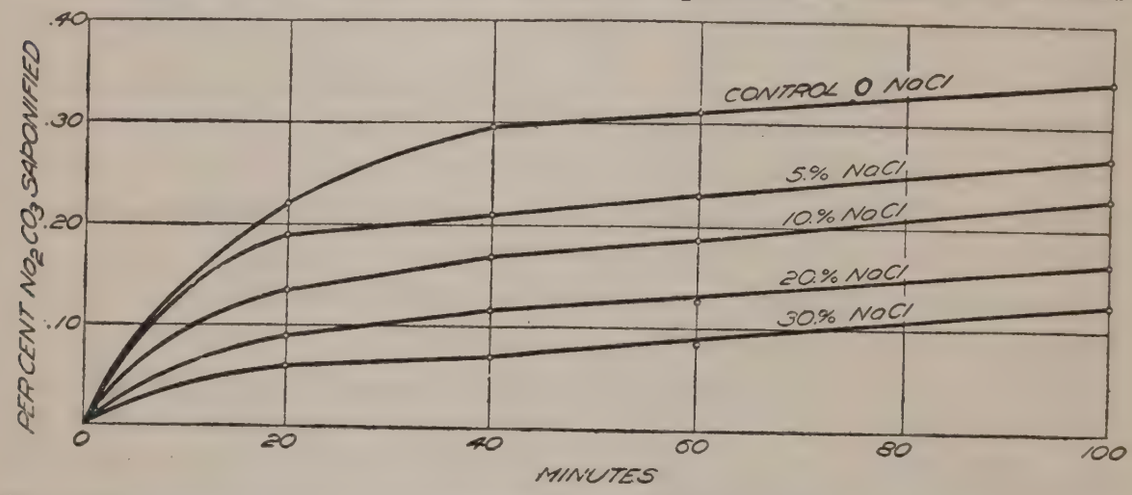

FIG. 25.—Graphs showing the saponification of ethyl acetate by sodium carbonate in the presence of sodium chlorid.

caustic when acting alone than when in the presence of either sodium chlorid or sodium sulphate.

In judging the amount of organic matter by the color of the solution in this and in preceding experiments the writer realizes that the method is far from satisfactory and that the data obtained do not represent the absolute amount of organic matter in solution. But the error in the determination would quite likely remain fairly constant in the different experiments, and, therefore, comparable results could be reasonably expected. This was all that was hoped for.

EFFECT OF LIME HARDPAN UPON FORMATION OF BLACK ALKALI

It is a well-known fact that a hardpan frequently accompanies black alkali. It has been commonly supposed that the black alkali is responsible for the hardpan, whereas in many cases the opposite may be true. If the hardpan is simply a puddled condition of the soil, the puddling might readily be brought about by the black alkali. In the case of the calcareous hardpan, with a sodium salt present, even if the top soil is not calcareous, black alkali might readily be produced in the following

manner. Suppose sodium chlorid is deposited on the surface in a crystalline form, and rain or irrigation water dissolves this and carries it down in a fairly concentrated form until the hardpan is reached. Here the evaporation of the water may further increase the concentration of the salt and the action upon the lime carbonate may take place in a rather concentrated solution. The black alkali, together with the soluble lime salt formed and the excess of the sodium chlorid is then, or thereafter, brought to the surface by the capillary action of the water. Here the sodium chlorid may again crystallize out upon the surface and be ready for the next rain or irrigation to carry it down through the soil for a further action upon the calcareous hardpan. This phenomenon was strikingly brought out in the experiment, illustrated in Plate 62, C. Two lantern chimneys were filled with pure quartz sand, and during the

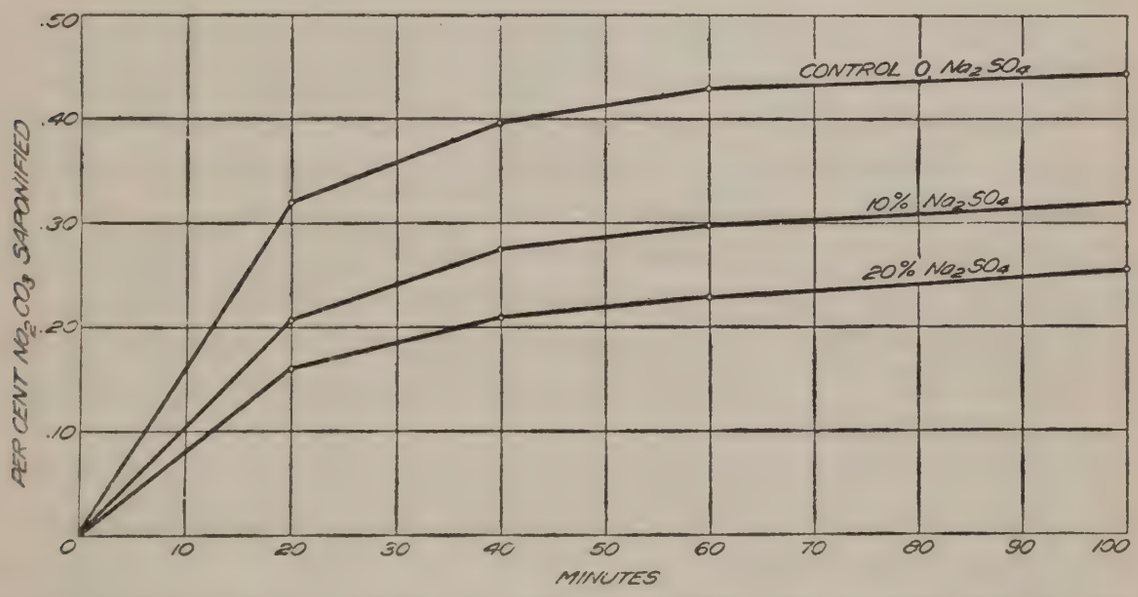

FIG. 26.—Graphs showing the saponification of ethyl acetate by sodium carbonate in the presence of sodium sulphate.

filling a thin layer of calcium carbonate was introduced into each. In No. 1 the bottom was stopped up and the layer of calcium carbonate placed at the lower end of the column; in No. 2 the calcium carbonate was placed about midway, and the bottom of the chimney closed with a strip of linen. No. 1 was then kept watered from the top with a 10 per cent solution of sodium sulphate, while No. 2 was placed in a large evaporating dish, containing some of the same sodium-sulphate solution. These chimneys illustrated two field conditions: One in which the calcareous hardpan is at the lower edge of the moisture plane, where under field conditions it would exist, the water having to penetrate the full depth of the soil to reach it; the other where the hardpan lies near the surface, the water, entering below, has to pass through the layer in order to reach the surface.

After several days sodium carbonate appeared on the surface of both chimneys of sand. In the case of No. 1, the sodium sulphate penetrated the sand until the calcium carbonate was reached, the reaction between

the two salts then took place ($Na_2SO_4 + CaCO_3 \leftrightarrows Na_2CO_3 + CaSO_4$), and the products of the reaction were brought to the surface by capillarity. In the case of No. 2, the sodium sulphate, coming up through the sand by capillarity, had to pass through the thin layer of calcium carbonate. At this point the same reaction took place, and the sodium carbonate was brought to the surface.

This experiment illustrates what often takes place in the field and is a possible explanation of why a lime hardpan almost invariably accompanies black alkali. The reverse of this, however, is not true. Black alkali does not always accompany hardpan, for the obvious reason that sodium chlorid or sodium sulphate are not always present in sufficient amounts in the soil or in the irrigation water to bring about the reaction.

CONCLUSIONS

(1) In the reaction between sodium nitrate (or sodium chlorid or sodium sulphate) and calcium carbonate, resulting in the formation of sodium carbonate, the presence of relatively small amounts of calcium nitrate or calcium chlorid in the reaction impedes and may prevent the formation of sodium carbonate.

(2) The presence of a saturated solution of calcium sulphate in this reaction does not entirely stop the formation of sodium carbonate.

(3) Sodium nitrate, sodium chlorid, and sodium sulphate in the presence of carbon dioxid react with calcium carbonate with the formation of sodium bicarbonate.

(4) The presence of relatively small amounts of calcium nitrate or calcium chlorid in this reaction impedes and finally prevents the formation of sodium bicarbonate.

(5) The presence of calcium sulphate has no effect in preventing the formation of sodium bicarbonate when sodium sulphate or a mixture containing sodium sulphate reacts with calcium carbonate.

(6) A field application of gypsum will probably have no effect in overcoming black alkali if the soil already contains soluble sulphates in appreciable amounts, or the irrigation water contains these salts.

(7) Sodium nitrate, sodium chlorid, and sodium sulphate increase the solubility of calcium carbonate in the soil.

(8) Sodium nitrate, sodium chlorid, and sodium sulphate react with calcium carbonate in the soil with the formation of sodium carbonate ("black alkali").

(9) Sodium carbonate, formed by the above reaction, decomposes the organic matter of the soil.

(10) Calcium carbonate has a slightly destructive action upon the organic matter of the soil.

(11) Sodium carbonate is much more destructive upon organic matter than sodium bicarbonate.

(12) The alkali crusts that accumulate upon the soil in some irrigated regions are due in part to the action of sodium salts upon calcium carbonate with the formation of sodium carbonate.

(13) Barren, or "slick," spots are often due to the action of sodium nitrate, sodium chlorid, or sodium sulphate upon calcium carbonate with the formation of sodium carbonate.

(14) Sodium chlorid and sodium sulphate have a protective action upon organic matter in the presence of sodium carbonate.

(15) A calcareous hardpan often produces black alkali.

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PLATE 62

A.—One-year-old lemon seedlings, showing the effect of additions of lime and manure to the soil: Pot 1, soil untreated; pot 2, 2 per cent of calcium carbonate added; pot 3, 1 per cent or manure added; pot 4, 1 per cent of manure and 2 per cent of calcium carbonate.

B.—Two-and-one-half-month-old lemon seedlings, showing the effect of alkali crust on ground: Pot 1, good grove, no crust; pot 2, poor grove, crust on surface.

C.—Reservoirs, showing the effect of a lime hardpan upon the formation of black alkali: 1, Hardpan ($CaCO_3$) at the lower edge of the moisture plane; 2, hardpan midway soil column.

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3
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A

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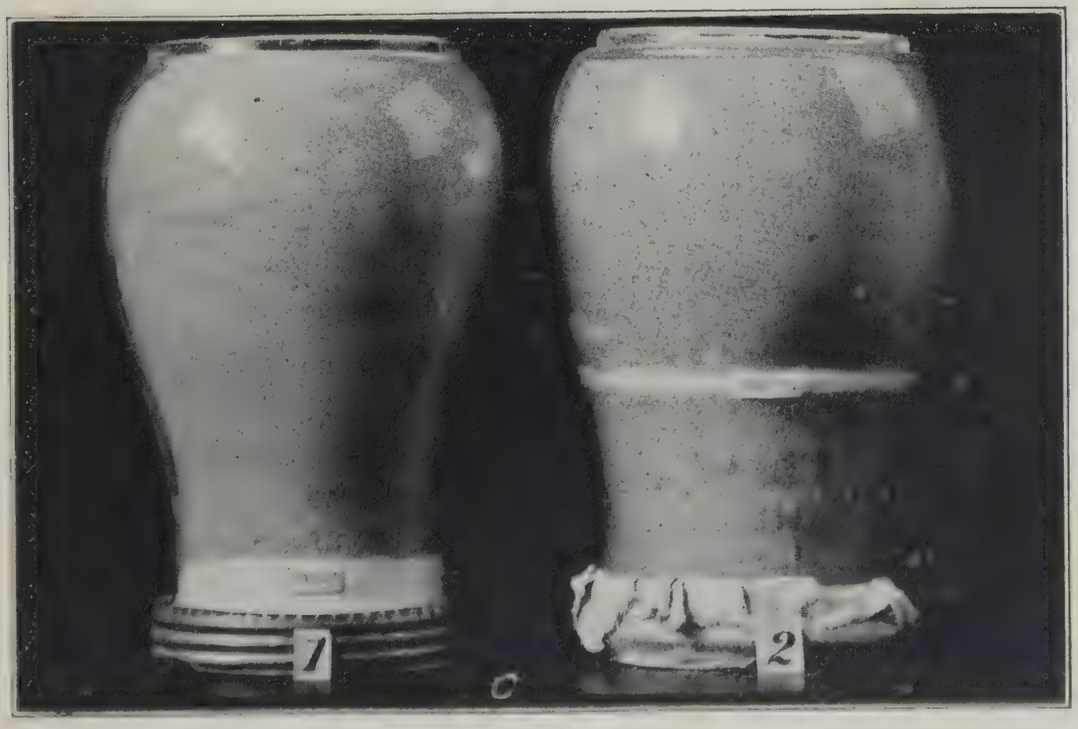
B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EFFECT OF THREE ANNUAL APPLICATIONS OF BORON ON WHEAT

By F. C. COOK, *Physiological Chemist, and* J. B. WILSON, *Assistant Chemist, Bureau of Chemistry, United States Department of Agriculture*

INTRODUCTION

The object of these experiments was to determine whether or not boron when applied to horse manure in quantities sufficient to act as a fly larvicide would have a cumulative action detrimental to wheat (*Triticum* spp.) grown on soil fertilized with this manure for three consecutive years.

EXPERIMENTAL WORK

Four plots of one-twentieth of an acre each on the farm of the Bureau of Plant Industry at Arlington, Virginia, were used for the experiments. One plot was used as a manured control and a second as an unmanured control. The third plot received manure plus borax, and the fourth manure plus colemanite. The manure was applied to all plots at the rate of 20 tons per acre, and the same variety of winter wheat was planted each year on all the plots. Borax was mixed with the manure the first year, (1913), at the rate of 0.33 pound per bushel. The last two years (1914 and 1915) the borax was mixed with the manure at the rate of 0.08 pound per bushel, and the colemanite was mixed with a second pile of manure at the rate of 0.095 pound per bushel.

It was calculated that when borax was mixed with manure at the rate of 0.08 pound per bushel and the manure applied at the rate of 20 tons per acre an equivalent of 0.0022 per cent boric acid (H_3BO_3) was present in the upper 6 inches of the soil. In the same way it was calculated for the colemanite plot that an equivalent of 0.0029 per cent of boric acid was present in the upper 6 inches of soil. The amount of borax added the first year, 0.33 pound per bushel, furnished 0.0088 per cent of boric acid to the upper 6 inches of soil.

The above figures show that the boron was applied as follows: The borax plot received boron the first year at the rate of 154 pounds of boric acid per acre and the second and third years at the rate of 38.5 pounds per acre. The colemanite plots received boron at the rate of 50.75 pounds of boric acid per acre each year.

Colemanite, a borate of lime, is found in the deposits of Ventura County, Cal. Its formula is $Ca_2B_6O_{11}\cdot 5H_2O$. On heating, the water is driven off, and it is reduced to a grayish white powder. The calcined colemanite is largely, but not entirely, insoluble in cold water. It is also likely that part of the calcium of the colemanite when added to the soil is precipitated as carbonate, and the boron in the compound thus acted upon is rendered soluble.

EFFECT OF THE BORON ON THE WHEAT

The wheat was planted each year in October a few days after the manure had been applied to the plots, and the growth was observed throughout the year. The crops were harvested the next June. Soil, straw, and grain samples were taken at the time of harvest for chemical analyses. The first year there was considerable yellowing of the young wheat plants in the borax plot, commencing in November and extending to the growing period the next spring, when it disappeared. This yellowing was not noticed the last two years when the amounts of boron added to the manure were reduced to amounts sufficient to act as a larvicide. There were no differences in the stand or appearance of the wheat on either the borax, colemanite, or manured control plots in 1915 or 1916. Each year the unmanured control showed the poorest stand. The yields of straw and grain from all the plots are given in Table I.

TABLE I.—*Yield of wheat at Arlington, Va., for three years, 1914–1916, from same plots ($\frac{1}{20}$ acre), fertilized annually with manure treated with borax and colemanite*

Treatment.	Yield (pounds).					
	1914		1915		1916	
	Straw.	Grain.	Straw.	Grain.	Straw.	Grain.
Manure and borax	204	104	159	89	284	79
Manure and colemanite	.....	.....	152	99	240	[a] 68
Manured control	234	116	173	103	204	72
Unmanured control	174	100	158	78	192	77

[a] These shocks were badly eaten by rats.

YIELDS OF STRAW AND GRAIN

The results in Table I show that the largest yield of grain was from the manured control plot, with the exception of 1916, when the borax plot showed the largest yield. The straw yield for 1916 was also highest on the borax plot, while the 1914 and 1915 straw yields were highest on the manured control. There was some loss from the colemanite plot in 1916 as rats ate part of the grain while it was standing in the field after cutting. A gradual reduction in the yield of grain each year from all plots is noticed. During 1916 there was a marked tendency toward the production of straw at the expense of grain, the ratios of straw to grain being 2 to 1 or under for 1914 and 1915, while it was 2.5 to 3 to 1

for 1916 on all plots. It is apparent that during 1914 and 1915, when there was a good growth on all plots, the borax had reduced the yield of grain over that of the manured control. The yields of grain from the borax plots both years were in excess of the yields from the unmanured control. The colemanite had little, if any, influence on the yields. During 1916, which was a poor year for wheat in this vicinity, the results do not show any effect of the boron. There was no apparent cumulative action of the boron in the soil. The yields of grain the first two years from the borax plots were 12 to 14 pounds under that of the manured control, while the third year (1916) the yield was 7 pounds more than that of the manured control.

ANALYSES OF STRAW AND GRAIN

In Table II are given results of the analyses of samples of straw and grain each year from all the plots. Water, ether extract, and nitrogen were determined by the methods of the Association of Official Agricultural Chemists.[1] The boric acid was determined in the straw and grain by the method described by the senior author (3, p. 879),[2] who used strips of paper dipped in an alcoholic solution of curcumin and compared the resulting color with that from standard solutions of boric acid.

TABLE II.—*Analyses of wheat straw and grain grown on plots fertilized for three years with manure containing added borax and colemanite, at Arlington, Va.*

Year.	Plot treatment.	Sample.	Constituents (per cent).			
			Moisture.	Ether extract.	Nitrogen.	Boric acid.
1914	Manure and borax.....	Grain.....	11.14	1.70	2.15	Trace.
		Straw.....	2.55	2.12	.28	Trace.
1915	.....do.....	Grain.....	9.18	1.71	2.21	0.00005
		Straw.....	4.88	1.13	.51	0
1916	.....do.....	Grain.....	9.10	.97	2.72	.0006
		Straw.....	5.87	.91	.62	.00070
1914	Manure and colemanite	Grain.....	.....	.....	.....	.....
		Straw.....	.....	.....	.....	.....
1915	.....do.....	Grain.....	9.76	1.80	2.40	.00008
		Straw.....	4.98	1.20	.58	0
1916	.....do.....	Grain.....	8.95	.99	2.84	.00025
		Straw.....	6.03	.92	.69	.00050
1914	Manured control.....	Grain.....	12.58	1.77	2.21	0
		Straw.....	2.53	2.27	.32	0
1915	.....do.....	Grain.....	9.60	1.55	2.24	0
		Straw.....	6.72	1.28	.48	0
1916	.....do.....	Grain.....	8.86	1.13	2.91	.0001
		Straw.....	5.53	.81	.70	Trace.
1914	Unmanured control....	Grain.....	.....	.....	.....	.....
		Straw.....	.....	.....	.....	.....
1915	.....do.....	Grain.....	.....	.....	.....	.....
		Straw.....	.....	.....	.....	.....
1916	.....do.....	Grain.....	9.12	1.13	2.56	Trace.
		Straw.....	4.90	.95	.49	Trace.

[1] WILEY, H. W., ed. OFFICIAL AND PROVISIONAL METHODS OF ANALYSIS, ASSOCIATION OF OFFICIAL AGRICULTURAL CHEMISTS. AS COMPILED BY THE COMMITTEE ON REVISION OF METHODS. U. S. Dept. Agr. Bur. Chem. Bul. 107 (rev.), p. 38–39. 1908.

[2] Reference is made by number to "Literature cited", p. 597.

Somewhat more boric acid was found in the grain and straw grown in 1916 than in that grown in 1915, while the smallest percentage of boric acid was found in the 1914 samples. Even after applying borax or colemanite to the same ground for 3 years, very little boron was taken up by the plants grown the third season. A little more boron was absorbed by the plants grown on the plots fertilized with manure containing borax than by the plants grown on the plots fertilized with manure to which colemanite had been added. In the pot tests reported by Cook (3) the same tendency for wheat plants grown on soil containing added borax to absorb more boron than plants grown on soil containing added colemanite was observed. The water figures were lower in the grain and higher in the straw each successive year, and there was a marked reduction each year in the ether extract of both wheat and straw from all plots, but an increased nitrogen content. The average figures show a little more water, fat, and nitrogen in the manured-control wheat and straw than in the borax-manure samples of wheat and straw.

The distribution of the boron between the grain and straw samples tested was nearly equal. In 1915 the roots of some plants from each plot were tested for boric acid with the following results: Borax plot 0.00007 per cent, colemanite plot 0.00007 per cent, and control plot 0.

ANALYSES OF SOIL SAMPLES

In Table III analyses of samples of soil taken from the various plots are recorded for each of the three years. The methods used for total nitrogen and ammonia (magnesium-oxid distillation process) were those of the Association of Official Agricultural Chemists.[1] The aeration method as outlined by Folin and Macallum (4) for the determination of ammonia and the nitrate method of the American Public Health Association (2) were employed. Both acid soluble and total boric acid were determined in each sample. For soluble boron 50 gm. of soil and 200 c. c. of 1–20 hydrochloric acid were shaken for one hour. The filtrate was made alkaline with lime, evaporated to dryness, and ashed. The ash was taken up in hydrochloric acid, diluted to 100 c. c. volume, and aliquots used for the colorimetric estimation of boron. The total boron was estimated by fusion of the soil sample with sodium hydroxid. In both cases the colorimetric method, with strips of curcumin paper, was employed for estimating the boron. It is apparent that the boron in the soil is combined in some insoluble form, such as a silicate, and can be estimated only by a fusion process.

[1] WILEY, H. W. Op. cit.

TABLE III.—*Analyses of samples of soil taken 8 inches deep from wheat plots at Arlington, Va., fertilized for three consecutive years with manure treated with borax and colemanite*

Year and treatment.	Per cent of nitrogen as—				Percentage of boric acid.	
	Total nitrogen.	NH_3 (MgO method).	NH_3 (Folin method).	NO_3.	Hydrochloric acid, soluble.	Total.
1914.						
Borax	0.09	0.004	.....	0.0018	0.003	.....
Control manured	.09	.003	.....	.0012	0	.....
1915.						
Borax	.175	.014	0.0017	.0010	0	0.00016
Colemanite	.140	.014	.0016	.0012	0	.00040
Control manured	.126	.028	.0016	.0020	0	Faint trace.
1916.						
Borax	.074	.021	.0007	.0009	0	.00018
Colemanite	.105	.025	.0007	.0009	0	.00024
Control manured	.112	.025	.0007	.0013	0	.00014

There is considerable variation in the total nitrogen results, undoubtedly due to the sampling. The nitrogen as ammonia, by the magnesium-oxid method, showed a gradual increase in all samples from 1914 to 1916. The ammonia results by the Folin aeration method were higher in the 1915 samples, where the highest total nitrogen results were obtained, than in the 1916 samples. The soil to which either borax or colemanite was added showed less nitrate nitrogen than the control samples for the years 1915 and 1916, while the borax-plot sample showed more nitrates than the control in 1914. The only sample that showed any boric acid soluble in weak hydrochloric acid was from the borax plot in 1914, following the very heavy application of borax that year. This plot showed a distinct injury to the wheat the same year. The results for total boric acid showed that considerably more boron was present in the soil to which boron had been added, either as borax or colemanite, than in the control soil; but no evidence of a cumulative action in the soil was found.

The colemanite plots showed more total boric acid than the borax plots. This is not surprising, in view of the fact that more total boron was added to the colemanite than to the borax plots.

BORON AND PLANT INJURY

Nakamura (5) tested the effect of borax on barley grown in pot cultures. He found that amounts of borax equivalent to 0.001 per cent of boric acid were toxic and that amounts of borax equivalent to 0.0002 per cent of boric acid produced slight injury.

Agulhon (1) grew wheat in pot cultures with sand and nutrient media to which he added varying amounts of boric acid. He found that 0.005 per cent of boric acid killed the wheat plants, while 0.001 per cent had no toxic effect.

Voelcker (6) in experiments with pots holding 40 pounds of soil, determined that 0.005 to 0.1 per cent of boric acid (H_3BO_3) and borax ($Na_2B_4O_7$) prevented the germination of wheat. He found that 0.001 per cent of either compound was harmful, but amounts from 0.0005 to 0.001 per cent were beneficial, the effectiveness increasing with the decreased percentage of boron.

In the field tests conducted by the writers at Arlington, Va., the presence of 0.0088 per cent of boric acid (added as borax) in the upper 6 inches of soil was toxic to wheat, while 0.0022 per cent added as borax, or 0.0029 per cent as colemanite was nontoxic to wheat.

It is interesting to recall that the soil sample taken nine months after the addition of the 0.0088 per cent of boric acid as borax in 1914 contained soluble boron. The other soil samples for three years and samples from this plot the next two years showed no detectable amounts of soluble boron and no injury to the wheat. The results of the analyses for soluble boron in soils from Orlando, Fla., New Orleans, La., and Dallas, Tex., to which borax had been added showed the presence of considerable amounts of soluble boron in the soils from Orlando and New Orleans where the crops had been decidedly injured by the borax. The crops at Dallas showed no injury, and no soluble boron was detected in the soil.

In brief, there appears to be a direct connection between the presence of soluble boron in soil and injury to plant growth. There is apparently a gradual combination of the soluble boron added to soil either as a silicate or calcium borate. The rapidity with which soluble boron becomes insoluble varies with each individual soil or soil type and with climatic and other factors.

SUMMARY

In field tests at Arlington, Va., based on the yield of the manured control plot, borax reduced the yield of wheat (grain) 10 per cent in 1914 and 1915, while colemanite had little, if any, effect. The manured control gave the largest yields of grain in 1914 and 1915, and the unmanured controls the lowest yields.

In 1916 the yields from all four plots were low, and the proportion of straw to grain was higher than during the two previous years. In 1916 the borax plot gave the best yield.

During the three years there were seasonal variations involving a gradual decrease of fat and an increase of nitrogen in the grain and straw from all plots. During this period the moisture in the straw increased and that of the grain decreased.

More boron was absorbed by the plants from the borax than from the colemanite plots, although only minute amounts of boron were absorbed by any of the wheat plants. The 1916 samples of straw and grain contained more boron than the 1914 and 1915 samples. In all samples a relatively uniform distribution of boron in the straw and grain was found.

A yellowing of the young plants was observed the first year (1914) on the borax plot. This directly followed a heavy application of borax manure to the plot, and the sample of soil from this plot taken nine months later showed the presence of soluble boron. In no other soil sample was any soluble boron found. Apparently the added borax is gradually combined in an insoluble compound and so distributed that the upper 6 inches of soil show little total boron after three yearly additions of borax. There were no evidences of any cumulative action of boron in the soil. It was apparently the soluble boron, not the total boron, in the soil that produced injury to the wheat plants.

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ENERGY VALUES OF HOMINY FEED AND MAIZE MEAL FOR CATTLE

By HENRY PRENTISS ARMSBY, *Director*, and J. AUGUST FRIES, *Assistant Director*,
Institute of Animal Nutrition of The Pennsylvania State College

COOPERATIVE INVESTIGATIONS BETWEEN THE INSTITUTE OF ANIMAL NUTRITION OF THE PENNSYLVANIA STATE COLLEGE AND THE BUREAU OF ANIMAL INDUSTRY OF THE UNITED STATES DEPARTMENT OF AGRICULTURE

INTRODUCTION

Hominy feed is a by-product of the milling of maize (*Zea mays*) for the production of hominy. In the winter of 1909–10 a series of 10 respiration calorimeter tests was carried out at the Institute of Animal Nutrition for the purpose of determining, by the methods outlined in a previous paper (2),[1] the net energy value of this by-product as compared with that of the maize from which it is manufactured. Some of the data obtained, together with earlier results on maize meal, were included with others in the general discussion of net energy values contained in the paper just referred to, but a review of these results and a more specific comparison of maize with its by-product, hominy feed, or hominy chop, including some more recent results on maize meal (3) seem desirable.

THE FEEDING STUFFS

As stated, hominy feed is a by-product of the manufacture of hominy or brewers' grits. In addition to their use as food, these products are used somewhat extensively by brewers and bakers. They are intended to consist substantially of the endosperm of the maize from which the hulls and germs have been completely separated. It is desired to reduce their percentage of fat to the minimum, and for this reason maize low in fat is preferred and special stress is laid upon the complete separation of the germ. White corn is used exclusively. It is first moistened to loosen the hull and then is passed through a machine called a "degerminator," which cracks the grains and is intended to remove the hulls and germs. The first separation, however, is incomplete, and from this point the material undergoes a process of gradual reduction and separation similar in its general outline to that used in the milling of wheat.

A comparison of the composition of our hominy feed,[2] as shown by analyses of two independent samples, with that of the hominy feed used

[1] Reference is made by number to "Literature cited," p. 613.

[2] Through the courtesy of the Miner-Hillard Milling Co., of Wilkes-Barre, Pa., we were able to obtain for experimental purposes a quantity of the freshly manufactured hominy feed and also of the maize from which it was made, and likewise to secure data as to the yield of the various products of the milling.

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by Lindsey (6, 7) in the digestion experiments hereafter referred to, and with Henry and Morrison's average of the composition of 778 samples (5, p. 633), is contained in Table I, from which it appears that our hominy feed was of normal composition.

TABLE I.—*Percentage composition of hominy feed, water-free*

Constituent.	Our analyses.	Lindsey's analyses.		Henry and Morrison's average.
		1904 and 1905.	1907.	
Ash	2.75	3.38	2.78	2.9
Protein [a]	9.33	[b] 12.23	[b] 11.59	[b] 11.8
Nonprotein [c]	1.29			
Crude fiber	5.13	4.97	5.28	4.9
Nitrogen-free extract	72.65	69.43	71.54	71.5
Ether extract	8.85	9.99	8.81	8.9
	100.00	100.00	100.00	100.0
Total nitrogen	1.83	.....	.....	.....
Carbon	47.31	.....	.....	.....
Heat of combustion per kilogram, Calories	4,709	.....	.....	.....

[a] Protein N×6.0. [b] Total N×6.25. [c] Nonprotein N×4.7.

The composition of the maize meal employed in this experiment (designated as experiment 211) and of that used in other experiments here, and likewise Henry and Morrison's average of 5,335 analyses (5, p. 633), is shown in Table II.

TABLE II.—*Percentage composition of maize meal, water-free*

Constituent.	Our experiments.			Henry and Morrison's average.
	Experiment 179.	Experiment 211.	Experiment 220.	
Ash	1.37	1.62	1.40	1.47
Protein [a]	9.94	9.29	9.78	[c] 10.48
Nonprotein [b]	0.48	0.24	0.28	
Crude fiber	2.60	3.16	2.04	2.59
Nitrogen-free extract	81.38	80.64	82.17	81.18
Ether extract	4.23	5.05	4.33	4.28
	100.00	100.00	100.00	100.00
Total nitrogen	1.758	1.60	1.689	.....
Carbon	45.03	46.80	46.16	.....
Heat of combustion per kilogram, Calories	4,431	4,517	4,505	.....

[a] Protein N×6.0. [b] Nonprotein N×4.7. [c] Total N×6.25.

The hay used in our experiments was mixed clover and timothy. In view of the rather low percentage of protein in the concentrates, a legume hay would probly have been preferable, had one been available. The

average composition of eight independent samples of the hay was as shown in Table III.

TABLE III.—*Percentage composition of mixed hay, water-free*

Constituent.	Composition.
Ash	7.01
Protein [a]	9.62
Nonprotein [b]	1.29
Crude fiber	33.78
Nitrogen-free extract	46.00
Ether extract	2.30
	100.00
Heat of combustion per kilogram..Calories..	4,396

[a] Protein N×6.25. [b] Nonprotein N×4.7.

PARTITION OF INGREDIENTS OF MAIZE

From a bushel (56 pounds) of maize there are obtained about 38 pounds of hominy, or grits, and about 18 pounds of by-products, consisting of—

(a) The hulls of the grains, together with the tips, derived from the cob.....about 2 pounds.
(b) The germs.....about 9 pounds.
(c) The starch immediately surrounding the germ and tip, which is necessarily scoured off in the various processes of grinding and screening.....about 7 pounds

These three products ground together constitute hominy feed. The percentages of the various products, therefore, are approximately—

Hominy		67.9
Hulls and tips	3.5	
Germs	16.1	
Scourings	12.5	
		32.1
		100.0

Partial analyses of samples of the hulls and tips, the germs, and the hominy were also made, with the results shown in Table IV.

TABLE IV.—*Percentage composition of milling products*

Product.	Total dry matter.	In dry matter.		
		Ash.	Nitrogen.	Carbon.
Hominy	86.60	0.50	1.46	45.03
Hulls and tips	91.42	1.92	1.41	47.81
Germs	91.02	5.95	2.49	50.60

From the foregoing figures the partition of the ingredients and of the energy of 100 pounds of maize between the several products of the milling may be computed to have been as shown in Tables V and VI. The outstanding differences are the considerable proportion of the nitrogen and the large proportion of the ash of the maize found in the hominy feed.

TABLE V.—*Partition of ingredients of 100 kgm. of maize*

Constituent.	Dry matter.	Ash.	Nitrogen.	Carbon.	Energy.
	Kgm.	*Kgm.*	*Kgm.*	*Kgm.*	*Therms.*
In 3.5 kgm. of hulls and tips..	3.20	0.06	0.04	1.53	.....
In 16.1 kgm. of germs.....	14.65	.87	.36	7.41	.....
In 12.5 kgm. of scourings....	8.30	.16	.11	4.34	.....
In 32.1 kgm. of hominy feed..	26.15	1.09	.51	13.28	123.14
In 67.9 kgm. of hominy.....	58.80	.29	.86	26.48	*a* 260.58
In 100 kgm. of maize.....	84.95	1.38	1.37	39.76	383.72

a By difference.

TABLE VI.—*Percentage partition of each ingredient*

Constituent.	Dry matter.	Ash.	Nitrogen.	Carbon.	Energy.
Hulls and tips.....	3.77	4.35	2.92	3.85	.....
Germs.....	17.25	63.04	26.28	18.64	.....
Scourings.....	9.77	11.59	8.03	10.91	.....
Hominy feed.....	30.79	78.98	37.23	33.40	32.09
Grits.....	69.21	21.02	62.77	66.60	67.91
Maize.....	100.00	100.00	100.00	100.00	100.00

ANIMALS

The experiments were made upon two steers. It was not found practicable to make the comparison on the same animal, since the experiment had other objects, but the two steers were of like breed and very similar in type, steer D being a grade Hereford, 33 months old, and steer G a full-blood Hereford, 38 months old.

GENERAL PLAN

Each animal received three different amounts of hay in as many periods, and from the data thus obtained the energy values of the hay were computed. In two additional periods steer D received a mixed ration of equal parts of hominy feed and mixed hay, and steer G a mixed ration of 1 part mixed hay and 2 parts maize meal. One of these two rations in each case was intended to be approximately a maintenance ration, while the other was as heavy a ration as it was found practicable

to feed. The results upon the concentrates were computed upon the assumption of unchanged utilization of the hay as computed from the three periods on hay alone.

Each period comprised 21 days, of which 11 were regarded as preliminary, while the visible excreta were collected quantitatively for the remaining 10. The complete balance of matter and energy was determined with the respiration calorimeter on the eighteenth and nineteenth days of each period. A list of the periods and rations fed and of the average live weights of the animals is contained in Table VII.

TABLE VII.—*Periods, rations, and live weights of experimental animals*

Period No.	Preliminary feeding.	Excreta collected.	Rations.			Average live weights.
			Mixed hay.	Hominy feed.	Maize meal.	
Steer D:	1909.		*Kgm.*	*Kgm.*	*Kgm.*	*Kgm.*
Period 1	Dec. 19–29	Dec. 30, 1909–Jan. 8, 1910.	7.0	.....	.....	460
	1910.	1910.				
Period 2	Jan. 9–19	Jan. 20–29	2.0	2.0	.....	432
Transition feeding.	Jan. 30–Feb. 5	.....	.....	.....	.....	.....
Period 3	Feb. 6–16	Feb. 17–26	4.5	4.5	.....	470
Transition feeding.	Feb. 27–Mar. 5	.....	.....	.....	.....	.....
Period 4	Mar. 6–16	Mar. 17–26	4.0	.....	.....	455
Period 5	Mar. 27–Apr. 6	Apr. 7–16	2.0	.....	.....	428
Steer G:						
Period 1	Jan. 2–12	Jan. 13–22	7.0	.....	.....	389
Period 2	Jan. 23–Feb. 2	Feb. 3–12	.9	.....	1.8	358
Transition feeding.	Feb. 13–19	.....	.....	.....	.....	.....
Period 3	Feb. 20–Mar. 2	Mar. 3–12	2.7	.....	5.4	398
Transition feeding.	Mar. 13–19	.....	.....	.....	.....	.....
Period 4	Mar. 20–30	Mar. 31–Apr. 9	3.6	.....	.....	387
Period 5	Apr. 10–20	Apr. 21–30	1.8	.....	.....	364

PERCENTAGE DIGESTIBILITY

The digestibility of the total rations and that of the grain as computed on the assumption that the hay consumed with it had the digestibility shown by the true average of the periods on hay alone was as shown in Table VIII.

TABLE VIII.—*Percentage digestibility of rations and of grain*

Animal and constituent.	Hay.				Mixed hay and grain.		Computed digestibility of grain.	
	Period 1.	Period 4.	Period 5.	Average.	Period 2.	Period 3.	Period 2.	Period 3.
Steer D (hominy feed):								
Dry matter	55.96	60.58	58.23	57.72	72.71	72.42	87.56	86.98
Ash	40.79	34.72	37.77	38.58	30.79	43.42	11.09	56.38
Organic matter	57.09	62.32	59.72	59.10	74.89	73.97	89.83	87.98
Protein	44.38	59.29	58.50	48.10	55.73	59.01	63.04	71.64
Crude fiber	52.09	59.31	55.21	54.76	61.09	54.92	101.94	55.94
Nitrogen-free extract	62.96	66.57	65.79	64.52	81.40	80.93	91.97	91.10
Ether extract	56.38	56.90	56.94	56.65	88.50	87.27	96.47	95.36
Total nitrogen	49.10	53.35	49.96	50.54	58.54	64.06	66.25	77.98
Carbon	52.98	58.52	56.32	55.18	72.65	71.91	89.33	88.03
Energy	52.80	58.17	55.43	54.84	72.35	71.60	88.52	87.17
Steer G (maize meal):								
Dry matter	59.23	60.06	59.02	59.44	80.72	72.73	91.63	79.55
Ash	51.44	37.05	34.25	45.13	27.23	36.22	—11.90	15.89
Organic matter	60.54	61.60	60.82	60.89	82.62	74.06	93.16	80.45
Protein	48.56	50.72	37.27	47.76	63.22	55.57	71.06	59.95
Crude fiber	56.91	59.36	57.52	57.72	65.13	51.15	105.80	14.92
Nitrogen-free extract	64.02	66.26	66.02	64.98	88.90	80.90	95.91	85.54
Ether extract	58.35	55.35	62.09	58.09	85.13	80.15	90.87	85.53
Total nitrogen	52.53	49.73	50.34	51.41	62.71	56.32	68.98	59.22
Carbon	57.21	57.61	57.35	57.34	80.61	72.37	92.35	79.82
Energy	56.61	57.24	56.32	56.75	79.98	71.56	91.55	78.96

The average percentage digestibility of the hay, as computed from the aggregate feed and excreta of the three periods, did not differ as between the two animals to a greater extent than is often the case. The differences as regards dry matter, organic matter, and energy are about 2 per cent, for nitrogen about 1 per cent, for crude fiber about 3 per cent, and for the remaining ingredients less than 1 per cent.

The heavier hay and grain rations of period 3 as compared with the lighter ones of period 2 show a slight decrease of digestibility in the case of steer D (on hominy feed), and a decided decrease with steer G (on maize meal). In the latter case it is to be noted that the difference in the quantity consumed was also greater than with steer D and that the ratio of grain to hay was also greater.

METABOLIZABLE ENERGY

The data obtained regarding the amount of chemical energy escaping in feces, urine, and methane, and the metabolizable energy remaining have already been published (2), but the principal results are repeated in Table IX for convenience.

TABLE IX.—*Losses of chemical energy—metabolizable energy*

Feed, animal, and period.	Energy per kilogram of dry matter.					Metabolizable energy per kilogram of digestible organic matter.	Percentage losses.			Percentage metabolizable.
	Total.	Losses.			Metabolizable.		In feces.	In urine.	In methane.	
		In feces.	In urine.	In methane.						
	Calories.	*Calories.*	*Calories.*	*Calories.*	*Calories.*	*Calories.*				
Hay:										
Steer D, period 1	4,400	2,077	209	285	1,829	3,442	47.20	4.75	6.49	41.56
Steer D, period 4	4,391	1,837	234	332	1,990	3,406	41.83	5.33	7.54	45.30
Steer D, period 5	4,390	1,956	255	345	1,834	3,294	44.57	5.80	7.85	41.78
Steer G, period 1	4,393	1,906	208	300	1,979	3,463	43.39	4.75	6.82	45.04
Steer G, period 4	4,391	1,878	220	319	1,974	3,420	42.76	5.00	7.27	44.97
Steer G, period 5	4,390	1,917	238	358	1,877	3,313	43.68	5.41	8.15	42.76
Average	4,393	1,929	227	323	1,914	3,390	43.92	5.17	7.35	43.56
Hay and hominy feed:										
Steer D, period 2	4,560	1,261	209	403	2,687	3,775	27.65	4.58	8.84	58.93
Steer D, period 3	4,553	1,293	196	340	2,724	3,879	28.40	4.30	7.47	59.83
Average	4,557	1,277	203	371	2,706	3,827	28.02	4.44	8.15	59.39
Hay and maize meal:										
Steer G, period 2	4,483	897	189	443	2,954	3,701	20.00	4.22	9.88	65.90
Steer G, period 3	4,468	1,271	156	352	2,689	3,763	28.45	3.49	7.88	60.18
Average	4,476	1,084	173	398	2,821	3,732	24.22	3.87	8.89	63.02
Hominy feed (computed):										
Steer D, period 2	4,720	542	195	496	3,487	3,993	11.48	4.13	10.50	73.89
Steer D, period 3	4,698	603	167	371	3,557	4,156	12.83	3.56	7.90	75.71
Average	4,709	573	181	433	3,522	4,075	12.15	3.84	9.20	74.81
Maize meal (computed):										
Steer G, period 2	4,526	382	175	509	3,460	3,776	8.45	3.87	11.25	76.43
Steer G, period 3	4,508	948	125	372	3,063	3,869	21.04	2.78	8.25	67.93
Average	4,517	665	150	441	3,261	3,822	14.74	3.32	9.75	72.19

With steer D the heavier ration of period 3 as compared with period 2 resulted in a slightly greater loss in the feces, which, however, was slightly more than offset by lessened losses in urine and methane, so that the percentage metabolizable in the total ration was practically the same. With steer G, on the contrary, the much heavier ration of period 3 caused a marked falling off in digestibility which was only partially compensated by smaller losses in the urine and methane, so that the percentage metabolizable was distinctly less.

HEAT PRODUCTION

The heat production as measured by the respiration calorimeter compared with that computed in the ordinary manner from the balance of carbon and nitrogen is shown in Table X.

TABLE X.—*Observed and computed daily heat production*

Animal and period.	Observed.	Computed.	Difference.	Computed ÷observed.
Steer D:	*Calories.*	*Calories.*	*Calories.*	*Per cent.*
Period 1 First day	11,276	11,951	675	106.0
Period 1 Second day	11,817	12,327	510	104.0
Period 2 First day	9,411	9,635	224	102.4
Period 2 Second day	9,782	9,992	210	102.1
Period 3 First day	13,845	13,593	252	98.2
Period 3 Second day	14,030	14,038	8	100.1
Period 4 First day	9,301	9,257	44	99.5
Period 4 Second day	9,092	9,198	106	101.2
Period 5 First day	7,899	7,940	41	100.5
Period 5 Second day	8,006	8,082	76	100.9
Steer G:				
Period 1 First day	11,669	11,601	68	99.4
Period 1 Second day	11,752	11,683	69	99.4
Period 2 First day	8,176	8,185	9	100.1
Period 2 Second day	8,218	8,275	57	100.7
Period 3 First day	13,307	12,829	478	96.4
Period 3 Second day	13,274	12,786	488	96.3
Period 4 First day	9,068	9,080	12	100.1
Period 4 Second day	8,806	8,806	0	100.0
Period 5 First day	6,938	6,786	152	97.8
Period 5 Second day	6,827	7,004	177	102.6

STANDING AND LYING

Standing and lying have been found to exert such an influence on the heat production of cattle that, in order to make comparisons, the observed results must be corrected to a uniform proportion of time standing and lying. The total heat production of each day of the 2-day periods has therefore been corrected to 12 hours' standing and 12 hours' lying in the manner described on page 454 of the paper already referred to (2) and the two days averaged. The distribution of this corrected heat production has also been computed by the method explained on page 468 of the same publication. The results of these computations are recorded in Table XI.

TABLE XI.—*Heat production corrected to 12 hours' standing*

Animal and period.	Dry matter eaten.		Corrected heat production.			Analysis of heat production.			
	Hay.	Grain.	First day.	Second day.	48-hour mean.	Standing 12 hours.	Rising and lying down.	Methane fermentation.	Remainder.
Steer D:	*Grams.*	*Grams.*	*Calories.*	*Calories.*	*Calories.*	*Calories.*	*Calories.*	*Calories.*	*Calories.*
Period 1	6,204	.....	11,775	12,995	12,359	1,679	79	805	9,796
Period 2	1,747	1,764	9,782	10,126	9,947	1,695	71	643	7,538
Period 3	3,910	3,949	14,877	15,040	14,936	1,850	102	1,216	11,768
Period 4	3,498	.....	9,481	9,680	9,625	1,498	76	527	7,524
Period 5	1,786	.....	8,291	8,259	8,258	1,497	57	282	6,422
Steer G:									
Period 1	6,092	.....	12,211	11,971	12,098	1,802	80	830	9,386
Period 2	790	1,542	8,678	8,362	8,470	1,505	74	470	6,421
Period 3	2,383	4,644	14,510	14,467	14,561	2,852	68	1,126	10,515
Period 4	3,149	.....	9,843	9,242	9,568	1,958	75	457	7,078
Period 5	1,608	.....	7,811	7,178	7,477	1,382	62	261	5,772

ENERGY EXPENDITURE CONSEQUENT ON FEED CONSUMPTION

It is a familiar fact that the consumption of feed tends to stimulate the metabolism of an animal, as is manifested by the increased amount of heat produced. The energy thus expended, as well as the chemical energy escaping in the excreta, must be deducted from the gross energy of a feeding stuff to obtain its net energy value. In this experiment the losses of energy in heat production per kilogram of dry matter, computed as in previous papers, are recorded in Table XII.

TABLE XII.—*Increment of heat production per kilogram of dry matter*

Feedstuff.	Animal, No.	Periods compared.	Total increment per kilogram.	Analysis of increment.			
				Standing 12 hours.	Rising and lying down.	Methane fermentation.	Remainder.
			Calories.	*Calories.*	*Calories.*	*Calories.*	*Calories.*
Mixed hay	D	1 and 5	928	41	5	118	764
Do	G	1 and 5	1,031	94	4	137	806
Average			980	67	5	123	785
Mixed hay and hominy feed	D	2 and 3	1,147	36	7	132	972
Mixed hay and maize meal	G	2 and 3	1,297	287	−1	140	871
Computed for hominy feed	D	2 and 3	1,365	30	9	146	1,180
Computed for maize meal	G	2 and 3	1,434	386	−4	146	906

One kgm. of maize dry matter appears to have caused a somewhat greater increase (about 5 per cent) in heat production than the same amount of hominy feed. A marked difference is manifested in the proportion of the increase due to standing, while the heat evolved by fermentation is substantially equal, and the direct stimulus to the metabolism ("remainder") is less with maize. The total difference is probably not very significant.

NET ENERGY VALUES

By subtracting from the gross energy of the hominy feed and maize meal, respectively, the losses of chemical energy in the feces, urine, and methane, as shown in Table IX, and the energy expenditure consequent upon its consumption as measured by the increment of heat production shown in Table XII, the following net energy values for the two feeding stuffs may be computed. Later investigations on maize meal (3), however, led to the conclusion that the figure obtained in this experiment for the heat expenditure in feed consumption was too high, and that 1,289 Calories per kilogram of dry matter was more nearly correct. The results in Table XIII are computed, using both factors.

TABLE XIII.—*Net energy values per kilogram of dry matter*

Feedstuff.	Gross energy.	Losses in excreta.	Expended in feed consumption.	Net energy value.
	Calories.	*Calories.*	*Calories.*	*Calories.*
Hominy feed	4,709	1,187	1,365	2,157
Maize meal	4,517	1,256	1,434	1,827
Maize meal, corrected result	4,517	1,256	1,289	1,972

COMPARISON WITH OTHER RESULTS

The results of this experiment indicate a distinct, although not great, superiority per kilogram of the hominy feed over the maize meal from which it was made. Before generalizing this conclusion it is obviously desirable to make such comparisons as are possible with results of other experiments.

AVERAGE RESULTS ON MAIZE MEAL

Additional determinations on the influence of maize meal upon the heat production, designated as experiments 179 and 220, have been reported from this Institute, and the results of 12 determinations of its digestibility have been averaged by Henry and Morrison (5). As Table II shows, the maize meal used in the trials just described did not differ materially in composition from that used in our other experiments nor from the composition shown by Henry and Morrison's average. The percentage digestibility of the ingredients of the samples of maize meal used in our several experiments (including the results already reported in Table VIII) is shown in Table XIV.

TABLE XIV.—*Percentage digestibility of maize meal*

Constituent.	Experiment 179.		Experiment 211.		Experiment 220.		
	Period 3.	Period 4.	Period 2.	Period 3.	Period 3.	Period 4.	Period 5.
Dry matter	64.91	76.23	91.63	79.55	89.78	81.54	90.63
Organic matter	66.26	77.68	93.16	80.45	90.15	82.37	91.55
Total nitrogen	63.68	61.58	68.98	59.22	69.68	59.21	71.77
True protein	57.05	58.01	71.06	59.95	74.74	65.46	76.34
Crude fiber	44.79	49.05	.....	14.92	76.27	17.42	8.68
Nitrogen-free extract	77.75	88.20	95.91	85.54	93.19	86.61	95.95
Ether extract	74.71	83.89	90.87	85.53	85.52	83.96	90.68
Energy	63.16	74.93	91.55	78.96	88.29	80.40	89.12

The results obtained in experiment 179, period 3, appear to have been abnormally low. The average of the 6 others, compared with Henry and Morrison's average of 12 experiments, is as follows (Table XV):

TABLE XV.—*Average percentage digestibility of maize meal*

Constituent.	Our experiments.	Henry and Morrison's average.
Dry matter	84.89	90
Organic matter	85.89	.....
Total nitrogen	65.07	74
True protein	67.57	.....
Crude fiber	27.72	57
Nitrogen-free extract	90.90	94
Ether extract	86.74	93
Energy	83.88	.....

Our averages are slightly lower than Henry and Morrison's. The latter did not include in their compilation experiments in which the nutritive ratio of the total ration was 1 to 12 or wider.[1] In all but one of our six experiments the nutritive ratio approached or passed 1 to 12, and this may account for the slightly lower digestibility. On the other hand, the lower digestibility in such cases appears to be due to a considerable extent to lessened fermentation of the carbohydrates and a correspondingly decreased loss of energy in methane, so that, as the writers have pointed out, a certain degree of compensation occurs as to the energy values and particularly as to the metabolizable energy per unit of digestible organic matter (2, p. 446, 451). It appears probable, therefore, that the factors for the latter quantity obtained in our experiments may be applied safely to other experiments also.

The metabolizable energy of maize meal in our experiments, computed as in Table IX (omitting experiment 179, period 3), was as shown in Table XVI. Henry and Morrison's results afford no data for a comparison of this sort.

TABLE XVI.—*Metabolizable energy of maize meal*

Experiment No.	Per kilogram dry matter.	Per kilogram digestible organic matter.
	Calories.	*Calories.*
Experiment 179, Period 4	3,392	3,716
Experiment 211, Period 2	3,460	3,776
Experiment 211, Period 3	3,063	3,869
Experiment 220, Period 3	3,334	3,753
Experiment 220, Period 4	3,129	3,851
Experiment 220, Period 5	3,200	3,543
Average	3,263	3,751

[1] Private communication

It would appear that the factor 3.9 therms per kilogram of digestible organic matter proposed by the writers (2, p. 453) for concentrates containing less than 5 per cent of fat is somewhat high for maize meal and that 3.8 would be more nearly correct. Applying the latter factor to Henry and Morrison's averages for the digestible nutrients, and using the average result for the heat increment per kilogram of dry matter which was reported in a previous paper—viz, 1.289 therms per kilogram dry matter—gives the results in Table XVII.

TABLE XVII.—*Energy values of average maize meal per kilogram dry matter*

	Calories.
Metabolizable energy	3,402
Energy expended in feed consumption	1,289
Net energy value	2,113

AVERAGE RESULTS ON HOMINY FEED

The composition of our sample, as shown by Table I, corresponded substantially to Henry and Morrison's average of 778 samples of high-grade hominy feed. No other determinations on the influence of hominy feed upon the heat production of an animal have been reported, but the average of nine determinations by Lindsey (6, 7) of its digestibility by sheep is given by Henry and Morrison (5, p. 647).

A reference to the original shows that the "English hay" used in eight out of the nine experiments was notably lower in protein than the mixed hay used in our experiments. Whether or not as a consequence of this lack of protein, three experiments out of the nine showed coefficients distinctly lower than the remainder—viz, for dry matter 71 per cent, 75 per cent, and 78 per cent. If these three apparently exceptional results are omitted, the average of the remaining six corresponds very well with our data, as Table XVIII shows.

TABLE XVIII.—*Percentage digestibility of hominy feed*

Constituent.	Lindsey's results.		Our results (two experiments).	Average of Lindsey's six and our two experiments.
	Nine experiments.	Six experiments.		
Dry matter	82.94	87.16	87.27	87.19
Organic matter	.....	.....	88.91	88.91
Total nitrogen	65.53	68.59	72.12	69.47
True protein	.....	.....	67.34	67.34
Crude fiber	75.60	87.87	78.94	85.64
Nitrogen-free extract	89.61	92.18	91.54	92.82
Ether extract	91.16	90.00	95.92	91.48

Regarding the figures of the last column of Table XVIII as representing the average digestibility of hominy feed, we may compute from the

average composition as shown in Henry and Morrison's compilation (Table I) the digestible organic matter. Multiplying the latter by the factor 4.075 Calories per gram obtained in our experiments, we may compute the energy values of average hominy feed to be as follows (Table XIX):

TABLE XIX.—*Energy values of average hominy feed per kilogram of dry matter*

	Calories.
Metabolizable energy	3,542
Energy expended in feed consumption	1,365
Net energy value	2,177

The results of the foregoing comparisons agree with those of Experiment 211 in giving a somewhat higher net energy value for hominy feed than for maize meal, although the difference is small in both cases, and in the average results hardly significant (Table XX).

TABLE XX.—*Average net energy values per kilogram of dry matter*

Feedstuff.	From experiment 211.	Computed from average results.
	Calories.	*Calories.*
Maize meal	1,972	2,113
Hominy feed	2,157	2,177

From the foregoing results and from the data contained in Table V it may be computed that the partition of the net energy of maize between the hominy and the total by-products included in the hominy feed is as follows:

TABLE XXI.—*Percentage partition of net energy of maize*

Feedstuff.	Computed from experiment 211.	Computed from average results.
In hominy feed	33.67	31.72
In hominy	66.33	68.28
In maize	100.00	100.00.

CORRECTION OF EARLIER TABLES

In three earlier publications (1, 4, 8) there has appeared a table of net energy values of feeding stuffs for cattle computed in the manner proposed by the writers (2, p. 486) from Henry and Morrison's figures for digestible nutrients (5, p. 653). The foregoing results indicate that the averages given in that table for maize and hominy feed require some correction.

In the case of maize the metabolizable energy was estimated at 3.9 Calories per gram of digestible organic matter as in the case of other similar concentrates. As shown above, the actual average is about 3.75 Calories per gram—that is, lower than that of other concentrates which have been experimented with—so that the tabulated results are somewhat too high.

In the case of the hominy feed an error was made, we believe, in the other direction by using too low figures for the average digestibility of this material. On the basis of the results here discussed, we submit the following corrections (Table XXII) for the table referred to:

TABLE XXII.—*Net energy values per 100 pounds (with average water content) for cattle*

Feedstuff.	As published.	Corrected.
	Therms.	*Therms.*
Maize, dent	89. 16	85. 50
Maize, flint	87. 50	84. 00
Maize meal	88. 75	85. 20
Hominy feed	81. 31	88. 78

SUMMARY

A comparison is reported of the metabolizable energy and of the net energy value of hominy feed as determined in an experiment on a grade Hereford steer with the corresponding values for maize meal ground from the same grain, as determined in a parallel experiment on a full-blood Hereford of about the same age. Data are also reported as to the partition of the ingredients and energy of maize meal among the products of its milling for the production of hominy.

An increase in the amount of the mixed ration of hay and hominy feed consumed resulted in a slightly decreased digestibility, while a greater increase in the amount of mixed hay and maize meal consumed caused a considerable decrease in digestibility.

The average percentage losses of energy in the excreta were greater with maize meal than with hominy feed, chiefly on account of the somewhat lower digestibility of the former, notably in the heavier ration.

The metabolizable energy per kilogram of dry matter and per kilogram of digestible organic matter was greater for the hominy feed than for the maize meal, the difference being due to the higher gross energy and smaller losses in the former case.

The increment of heat production by the animal per kilogram of dry matter consumed was slightly less for the hominy feed than for the maize meal but slightly greater than the average of all experiments on the latter material.

The net energy value of the hominy feed in this experiment was distinctly greater than that of the maize meal. A computation of the net

energy values based on the average composition and digestibility of the two materials reduced this difference to an insignificant amount.

Corrections are reported for the net energy values of hominy feed and maize meal contained in earlier tables.

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FURTHER STUDIES OF THE MOSAIC DISEASE OF TOBACCO

By H. A. Allard,

Assistant Physiologist, Tobacco and Plant-Nutrition Investigations, Bureau of Plant Industry

SUSCEPTIBILITY OF PLANTS TO INFECTION THROUGH THE TRICHOMES

The virus of the mosaic disease of tobacco (*Nicotiana tabacum*) is readily inoculated into the tissues of healthy plants. The disease may be easily communicated by means of a needle through the roots, the stems, or the leaves. It is interesting to note that inoculations are also successful when the virus is introduced into susceptible plants through the trichomes of the leaves alone. Experiments have shown that a very high percentage of infection may be obtained when the virus is painted or rubbed lightly upon the leaves with a soft brush.[1]

The following experiments (Table I) make this fact plain. Young plants of the Connecticut Broadleaf variety growing in 3-inch pots were used in all tests.

Table I.—*Experiments showing infectivity of the virus when inoculated into the trichomes of leaves of tobacco plants*

Number of plants.	Date of inoculation.	Treatment.	Results.
	1915.		
10.....	Aug. 23	Virus painted on several leaves with a camel's-hair brush.	First symptom August 28; 10 mosaic September 3.
10 (control)..	...do.....	Healthy sap painted on one leaf with a camel's-hair brush.	All healthy September 3.
10.....	Aug. 27	Virus painted lightly on the trichomes of one leaf only with a camel's-hair brush.	First symptom September 1; 10 mosaic September 7.
10.....	...do.....	Tips of trichomes on the smallest, inmost leaf pinched and bruised with forceps moistened with the virus of mosaic. The leaf surface was not touched.	First symptom September 1; 5 mosaic September 7.

[1] Clinton has observed that the mosaic disease of tobacco is readily communicable to healthy plants by rubbing the virus upon the leaves. (Clinton, C. D. chlorosis of plants with special reference to calico of tobacco. *In* Conn. Agr. Exp. Sta. Rpt. 1914, p. 357–424, pl. 25–32. 1915.)

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TABLE I.—*Experiments showing infectivity of the virus when inoculated into the trichomes of leaves of tobacco plants*—Continued

Number of plants.	Date of inoculation.	Treatment.	Remarks.
	1915.		
10 (control)..	Aug. 27	Tips of the trichomes of the youngest leaves pinched and crushed with forceps dipped in healthy sap and tap water.	All healthy September 7.
10.....	Aug. 28	Fresh virus rubbed lightly on the trichomes of two of the youngest leaves with a brush.	First symptom September 2; 10 mosaic September 7.
10.....	...do.....	Trichomes pinched and bruised with forceps moistened with virus of mosaic.	10 plants mosaic September 7.
10 (control)..	...do.....	Trichomes pinched and bruised with sterilized forceps dipped in healthy sap and tap water.	All healthy September 7.
10.....	Aug. 29	Fresh virus punctured into several leaves with a needle.	9 mosaic September 7.
10.....	...do.....	Trichomes of the smallest leaves pinched and crushed with forceps dipped in the virus of mosaic.	6 mosaic September 7.
10.....	...do.....	.....do.....	8 mosaic September 7.
10 (control)..	...do.....	Tap water and fresh healthy sap inoculated into the leaves with a needle.	All healthy September 7.
10.....	Aug. 30	Tips of the trichomes of the smallest, inmost leaves cut with small scissors and fresh virus carefully introduced upon the cut surface.	First symptom September 1; 9 mosaic September 7.
10.....	...do.....	.....do.....	7 mosaic September 7.
10.....	...do.....	.....do.....	9 mosaic September 7.
10 (control)..	...do.....	Tap water and healthy sap painted upon the trichomes of the leaves.	All healthy September 7.

It is evident that the infective principle very readily enters a plant through the trichomes, if these are broken or bruised. The readiness with which plants may be affected in this manner accounts for the high percentage of infection obtained in the touching and handling experiments of earlier investigators working with the mosaic disease of tobacco.

The following experiments indicate that the infective principle of the disease may also be extracted from the trichomes of mosaic plants. On October 23, 1915, the trichomes of the youngest leaves of a mosaic plant were carefully cut with small scissors previously sterilized by boiling. The trichomes of the youngest leaves of a healthy plant were then cut with the same scissors. In this process of cutting the trichomes are more or less bruised and macerated. This operation was repeated, with healthy and mosaic plants alternately, until 10 healthy plants were treated in this manner. Eight of the healthy plants so treated were mosaic on November 3, 1915. Ten control plants treated in the

same manner—that is, by cutting the trichomes of healthy plants with sterilized scissors—remained healthy. The preceding test was again repeated with the trichomes of mosaic plants on October 30, 1915. Of the 10 plants thus treated, 5 were mosaic on November 27, 1915. All controls remained healthy.

EFFECT OF SPRAYING AND DROPPING THE VIRUS UPON THE LEAVES OF TOBACCO PLANTS

All experiments indicate that the infective principle of the mosaic disease of tobacco does not readily invade uninjured trichomes or leaf tissues. Although infection sometimes follows when the virus is merely sprayed upon the leaves with an atomizer, or dropped carefully upon the surface at one or two points, this appears to be a very uncertain method of producing infection in healthy plants. If, on the other hand, the virus is sprayed upon the leaves and subsequently rubbed in, infection readily follows, probably from the fact that the trichomes are more or less injured (Table II).

TABLE II.—*Effect of spraying and dropping the virus upon the leaves of 10 Connecticut Broadleaf tobacco plants*

Treatment.	Date inoculated.	Results.
	1915.	
Fresh virus sprayed upon leaves with an atomizer..	Sept. 15	4 mosaic.
Virus rubbed upon trichomes.....	...do.....	10 mosaic.
Control. Inoculated with tap water.....	...do.....	All healthy.
Fresh virus sprayed upon leaves till moist.....	Dec. 28	Do.
Fresh virus sprayed upon the leaves as in the preceding test and the leaf surfaces then rubbed with a stiff brush.	...do.....	8 mosaic.
Leaf surface rubbed with cut end of petiole of a green mosaic leaf.	...do.....	10 mosaic.
One drop of fresh virus dropped carefully on one leaf.	...do.....	All healthy.
One drop of fresh virus dropped on one leaf as in the preceding test and rubbed in at this point.	...do.....	1 mosaic.
Control. Leaf surfaces rubbed with cut end of petiole of a healthy leaf.	...do.....	All healthy.

EFFECT OF ONE AS COMPARED WITH SEVERAL INOCULATIONS

Various experiments have shown that infection is more likely to follow if the virus is inoculated into the plants at more than one point. As shown in Table III, the percentage of infection is highest in those tests where many inoculations have been made.

It is rather interesting to note that, even though the virus be introduced into each plant of a series at many points, it is not unusual for some plants to escape infection.

TABLE III.—*Effect of one inoculation as compared with several inoculations in young plants. Inoculations made with a needle, introducing the virus into each puncture*

Number of plants inoculated.	Number of inoculations.	Distribution of inoculations.	Date inoculated.	Result.	Percentage mosaic.
			1915.		
77 Maryland Mammoth..	1	One in one leaf	Jan. 13	5 mosaic	6
76 Maryland Mammoth..	2	One in each of two leaves	...do...	22 mosaic	28
54 Maryland Mammoth..	1	One in one leaf	...do...	6 mosaic	11
44 Maryland Mammoth..	2	One in each of two leaves	...do...	25 mosaic	56
103 Maryland Mammoth.	1	One in one leaf	Jan. 9	13 mosaic	12
109 Maryland Mammoth.	3	Two in one leaf; one in a second leaf.	...do...	71 mosaic	65
41 (first-generation hybrid).	1	One in one leaf	...do...	3 mosaic	7
54 Maryland Mammoth..	Many.	In all the leaves	...do...	45 mosaic	83
50 Connecticut Broadleaf.	1	In middle of one leaf near midrib..	May 8	7 mosaic	14
Do	Many.	In all the leaves	...do...	50 mosaic	100
10 Connecticut Broadleaf.	1	One in middle of one leaf near midrib.	Aug. 24	All healthy..	.....
Do	2	Two in one leaf, one on each side midrib near middle.	...do...	.....do.....	.....
Do	3	Two in one leaf, one in second at middle near midrib.	...do...	1 mosaic	10
Do	4	Two in each of two leaves near middle, and one on each side midrib.	...do...	.....do.....	10
Do	Many.	In all the leaves	...do...	7 mosaic	70
Do	Many.	With tap water in all the leaves (control).	...do...	All healthy..	.....
Do	1	One in one leaf	Dec. 21	3 mosaic	30
Do	2	One in each of two leaves	...do...	5 mosaic	50
Do	3	One in each of three leaves	...do...	3 mosaic	30
Do	4	One in each of four leaves	...do...	8 mosaic	80
Do	5	One in each of three leaves; two in a fourth.	...do...	.....do.....	80
Do	6	Two in each of three leaves	...do...	9 mosaic	90
Do	7	Two in each of three leaves; one in a fourth.	...do...	8 mosaic	80
Do	8	Two in each of four leaves	...do...	6 mosaic	60
Do	10	Two in each of four leaves; one in a fifth.	...do...	9 mosaic	90
			1916.		
Do	1	One in one leaf	Jan. 31	All healthy..	.....
Do	2	One in each of two leaves	...do...	3 mosaic	30
Do	3	Two in one leaf; one in a second leaf.	...do...	4 mosaic	40
Do	4	Two in each of two leaves	...do...	5 mosaic	50
Do	5	Three in two leaf; two in a second leaf.	...do...	6 mosaic	60
Do	6	Two in each of three leaves	...do...	5 mosaic	50
Do	8	Four in each of two leaves	...do...	.....do.....	50
Do	10	Five in one leaf; three in a second leaf and two in a third leaf.	...do...	10 mosaic	100
Do	12	In all the leaves	...do...	9 mosaic	90
Do	15	.....do.....	...do...	10 mosaic	100
Do	20	.....do.....	...do...	8 mosaic	80
Do	20	With tap water in all the leaves	...do...	All healthy..	.....
Do	Many.	.... do.....	...do...	.....do.....	.....

THE QUESTION OF RESISTANCE TO MOSAIC DISEASE IN TOBACCO PLANTS

In a series of plants, even though a large number of inoculations may be made in the leaves of each plant as nearly as possible in the same manner, a few plants may escape infection and remain free from the disease until maturity.

Experiments have been carried out to determine whether such plants produce progenies which are more or less resistant to the disease. In one series 50 young Connecticut Broadleaf plants were inoculated at one

point in a single leaf. Fifty similar plants were also inoculated at 20 points in several of the largest growing leaves. A very small percentage of the plants receiving a single inoculation became infected with the mosaic disease. In the series receiving 20 inoculations a few plants failed to become infected with the disease. Two plants which became infected from a single inoculation and five plants which remained free from the disease until maturity after 20 inoculations were allowed to produce seed. Seed of each plant was sowed separately, and a series of young plants from each mother was inoculated once in a single leaf. In these tests progenies of the mother plants which escaped infection after 20 inoculations did not give any evidence of greater immunity to the mosaic disease than progenies from the mother plants which became diseased from a single inoculation. It is difficult to explain why some plants fail to become infected with the virus even after many thorough needle inoculations have been made. Other experiments have shown that even these apparently resistant plants may readily succumb to later inoculations, for if they are more resistant than others, it seems to be a resistance of a more or less temporary nature. Even in the field, where the mosaic disease is very widespread, a few plants may be found which escape the disease. Whether or not such plants have escaped infection, or are actually more resistant than others, can not be determined until experimental inoculations have been made. Investigations dealing with large numbers of plants along this line would perhaps throw light on the question of relative resistance of different individuals.

Different individuals of the same strain may show different degrees of expression of the disease. One plant may show the mottled phase particularly well developed. A sister plant may show extreme stunting and the development of depauperate leaves and blossoms. These differences appear to depend upon constitutional differences in individual plants rather than upon differences in the degree of virulence of the virus. Inoculation experiments indicate that the virus extracted from the slightly mottled plant produces essentially the same type of disease in young plants as is obtained from the virus of plants showing the most extreme stunting and malformation of the leaves. Individual differences in the expression of the disease in the same strain are probably analagous to those differences observed when plants of different genera of the solanaceous family become infected with the mosaic disease.

Certain characteristics associated with the expression of the mosaic disease of tobacco are more or less dependent upon unfavorable conditions of growth. Plants showing the mottled phase in the field when transplanted to the greenhouse often develop depauperate leaves and blossoms. Although the blossoms may be beautifully mottled, it is very rare to find catacorolla showing in field plants, however badly they may be affected with the disease. When these plants are transferred to pots or beds in the greenhouse in the fall and are cut back severely, the most

extreme forms of malformation of the leaves and catacorolla frequently come into expression. The blossoms and leaves of healthy plants given the same treatment remain normal indefinitely.

SUBSEQUENT DISTRIBUTION OF THE VIRUS OF MOSAIC IN INOCULATED LEAVES AFTER CUTTING THE MIDRIBS OR LATERAL VEINS

In February, 1914, a series of tests was made to determine the effect of severing the midrib or the lateral veins upon the subsequent distribution of the virus in an inoculated leaf. In one series the midrib alone was carefully severed close to the base of the leaf blade (Pl. 63, leaf A).

In a second series the lateral veins were cut in the same manner along either side of the midrib (Pl. 63, leaf B).

In a third series a cut was made close to the midrib from a point near the apex nearly to the base on one side of the leaf, thus severing all the larger lateral veins on this side (Pl. 63, leaf C).

A sharp scalpel heated to redness was used for all cutting. This method not only insures complete sterilization of the instrument, but also serves to kill the tissues immediately in contact with the blade, thus searing over the freshly cut surfaces. After a brief wilting, turgidity is again established and growth and assimilation maintained, although more slowly, as would be expected (Table IV).

TABLE IV.—*Effect of severing the midrib or lateral veins, following inoculation, upon the distribution of the virus in the plant*

Number of plants treated.	Treatment.	Date treated.	Results.	Incubation period.
		1914.		*Days.*
13 Connecticut Broadleaf.	Inoculated at several points on either side of midrib near apex of leaf. Midrib then severed at base (Pl. 63, leaf A).	Feb. 7	9 mosaic, Feb. 27–28.	20–21
10 Connecticut Broadleaf.	.....do.....	...do.....	3 mosaic, Mar. 2–3...	26–27
Do.....	Inoculated at several points near middle of both halves of leaf near margins. Lateral veins then cut on both sides midrib from a point near apex nearly to base (Pl 63, leaf B).	...do.....	5 mosaic, Feb. 26–28.	19–21
Do.....	Inoculated at several points near middle of one-half of leaf near margin. This half cut away from midrib at a point near apex nearly to base (Pl. 63, leaf C).	...do.....	First symptom, Mar. 1–2.	24–25
15 Connecticut Broadleaf.	Inoculated at several points near apex of leaf only.	...do.....	6 mosaic, Feb. 25–27.	18–20
10 Connecticut Broadleaf.	Control. Inoculated with healthy sap at several points near middle of one-half of leaf close to margin. Lateral veins cut as in leaf B, Plate 63.	...do.....	All healthy.....	
19 Connecticut Broadleaf.	Inoculated at several points near apex, and midrib severed at base.	Feb. 20	11 mosaic, Mar. 4–5..	[a] 15
Do.....	Inoculations made as in preceding test, but midrib not severed.	...do.....	10 mosaic, Mar. 4–5..	[a] 15

[a] About.

On February 25, 1914, five plants, three of which were White Burley and two Maryland Mammoth, were inoculated at the middle of one-half of a leaf near the margin and cut along the same side of the midrib as in leaf C, Plate 63. Five similar plants were inoculated in the same manner without cutting the leaf blade along the midrib. The disease made its appearance in these two lots of plants as follows:

Series inoculated and cut along the midrib:
- Two White Burley plants became mosaic 11 days after inoculation.
- One White Burley plant became mosaic 14 days after inoculation.
- Two Maryland Mammoth plants became mosaic 18 days after inoculation.

Series inoculated but not cut along the midrib:
- One plant remained healthy.
- One White Burley plant became mosaic 10 days after inoculation.
- Two Maryland Mammoth plants became mosaic 10 days after inoculation.
- One Maryland Mammoth plant became mosaic 18 days after inoculation.

These tests are sufficient to show that cutting across the midrib or severing all the larger lateral veins on one or both sides of the midrib does not prevent the final dissemination of the virus from distant points of inoculation in the leaf to other leaves of the plant. Although it is possible that the virus dose not travel as rapidly following this treatment, the differences do not appear to be consistently and strikingly conspicuous. Even though cutting across the midrib near the petiole permanently interrupts the main vascular system of the leaf, yet multiplication and diffusion of the virus from cell to cell, aided perhaps by the finely anastomosing lateral veins would sooner or later allow the virus to reach the petiole and pass into the rest of the plant. To what extent the virus of mosaic is carried directly through the vascular system, along with the transpiration stream is not known.

REMOVAL OF THE VIRUS FROM THE HANDS BY THOROUGH WASHING

In the following experiments the hands were covered with fresh virus before handling the plants. Each leaf of a series of 10 plants was then rubbed vigorously between the fingers. Following this treatment the hands were washed thoroughly several times with soap and water and wiped dry. The leaves of young, healthy plants were then rubbed between the fingers as before. The results in Table V show that this is a practical and efficient means of removing infection from the hands.

TABLE V.—*Effect of washing the hands thoroughly with soap and water to remove the mosaic-disease virus. Inoculations made on January 31, 1916, with series of 10 young Connecticut Broadleaf tobacco plants*

Number of plants.	Treatment.	Results.
10	Leaves rubbed and pinched between the fingers after dipping the fingers in fresh virus.	10 mosaic.
10	Hands were washed with soap and water, but left wet. Leaves rubbed and pinched as before.	2 mosaic.
10	Hands again thoroughly washed with soap and water and carefully dried. Leaves handled as before.	All healthy.
10	Hands again covered with fresh virus and leaves handled as before.	10 mosaic.
10	Hands now thoroughly washed with soap and water and carefully wiped dry. Leaves handled as before.	All healthy.
10	Hands again dipped into fresh virus and leaves handled as before.	4 mosaic.
10	Hands not washed but merely wiped dry. Leaves handled as before.	1 mosaic.
10	Plants inoculated with tap water, using a needle.....	Do.

SOIL STERILIZATION IN THE SEED BED AND THE OCCURRENCE OF THE MOSAIC DISEASE

In the field the mosaic disease may make its appearance regardless of the type of soil or previous crop conditions. So far as soil infection is concerned, there seems to be no direct relation to previous outbreaks of the disease, either in the seed bed or in the field. As a matter of fact, thorough sterilization of the seed bed with steam does not necessarily control the occurrence of the disease in the field, as experiments carried out at Arlington, Va., in 1915, have shown. Mr. E. G. Beinhart, of the Office of Tobacco Investigations, contributes the following data relative to this sterilization:

A bed was newly made on a clay soil. Over the clay a mixture of sand, peat, and compost was laid to a depth of 8 inches, and the fertilizers were worked in before steaming was begun. Steam was furnished by a road roller which gave an average pressure of 100 pounds, the range being from 80 to 125 pounds.

In these experiments the following temperature relations were obtained:

TABLE VI.—*Temperatures secured at Arlington, Va., in 1915, in five different parts of a tobacco seed bed sterilized with steam. Readings taken immediately after lifting the pan, as well as one hour later*

Depth.	Reading taken.	Temperatures obtained.				
		1.	2.	3.	4.	5.
		°C.	°C.	°C.	°C.	°C.
Surface	Immediately after lifting pan.	100	100 – 101	99	99	100
Do	One hour later	96	96	.....	.....	.....
3 inches	Immediately after lifting pan.	99	.....	98	97	.....
Do	One hour later	99	.....	.....	.....	.....
4 inches	Immediately after lifting pan.	.....	99	.....	.....	80
Do	One hour later	.....	98	.....	.....	.....
6 inches	Immediately after lifting pan.	80	84	92	90	70
Do	One hour later	86	94	.....	.....	.....
10 inches (subsoil.)	Immediately after lifting pan.	22	22	.....	.....	.....
Do	One hour later	30	.....	.....	.....	.....

At Mr. Beinhart's suggestion some green mosaic leaves, freshly picked, were buried in the soil at a depth of 4 inches during the process of sterilization. Likewise, fresh mosaic virus, mixed in certain proportions with soil, was also buried to a depth of 4 or 5 inches at the same time. Inoculation tests made at once showed that the leaves which were cooked to the point of disintegration, had completely lost their infectious properties, as well as the virus mixed with the soil. In control tests, the same virus mixed with soil in the same proportions, but not subjected to sterilization, remained highly infectious, as did unsterilized portions of green mosaic leaves from the same plants.

Although these experiments with buried mosaic material indicate the thoroughness of steam sterilization, practically every plant obtained from these beds and set in the field at Arlington, Va., sooner or later became mosaic diseased. Late in the season the mosaic disease also made its appearance in the beds themselves at some points. The occurrence of the disease in a thoroughly sterilized soil can not be reasonably explained on any other basis than that of infection reaching the plants from sources external to the soil.

RELATION OF THE MOSAIC DISEASE TO INFECTION IN THE SOIL

Although the mosaic disease is readily communicated to healthy plants by inoculation of the virus into the roots, the disease does not necessarily follow as a result of introducing large quantities of mosaic material into the soil so that the roots must ultimately reach it. Under such conditions the disease frequently does not occur at all, although in some experiments the buried, decomposing material still retained its infectious properties, as shown by inoculation tests. Infection from such material in the soil appears to depend upon injury to some portion of the root

system which allows the virus to gain an entrance at these points. Experiments have shown that the promptness and certainty of infection are greater when the green mosaic material is thoroughly mixed with the entire mass of soil just before transplanting than when it is buried carefully in the lower layers. The explanation seems to be that in the former case the injured roots of plants during transplanting are more likely to come directly in contact with infective material. In the latter case the injured roots are given an opportunity to heal before any portion of the extensive root system reaches the layers of mosaic material, and for this reason infection is greatly delayed, should it take place at all. Many healthy plants have been grown to maturity under these conditions, although an examination has shown that the roots have penetrated every portion of the layer of mosaic material. In fact, owing to the availability of additional plant food through the decomposition of the mosaic material, the plants have generally shown greater vigor and a darker green color than control plants which received no vegetable material.

In a long series of experiments the effect of replacing mosaic plants grown in 12-quart pails by young, healthy plants was studied. The results were rather uncertain and showed that healthy plants do not necessarily become mosaic, even though they immediately replace mosaic plants. In some instances several successive plants have developed the mosaic disease shortly after transplanting, followed by one or more plants which remained healthy. Here, also, immediate infection probably depends upon the fact that the injured roots of healthy transplanted seedlings in some instances happen to come directly in contact with some portion of the broken mosaic root system of the diseased plant just removed.

It is quite possible that injury due to underground parasites may be a factor in facilitating root infection in the mosaic disease of tobacco. During a series of pail experiments with plants grown in soil, to the lowermost layers of which chopped up mosaic leaves and stems had been added, the root systems of some of the plants became badly infested with nematodes. It is believed that their attacks were a factor in producing some of the infection which followed in these instances. Since it is known that the larval stages of tobacco flea-beetles feed upon the finer roots of tobacco and other solanaceous plants, it would be of considerable interest to know whether or not these parasites are able also to communicate the disease from the root systems of mosaic to healthy plants in the field.

BEHAVIOR OF NICOTIANA GLAUCA AFFECTED WITH THE MOSAIC DISEASE

It was at one time thought that *Nicotiana glauca* is immune to the mosaic disease of tobacco. It is now known that this species does acquire the disease by artificial inoculation, although perhaps less readily

than do varieties of *N. tabacum*. The symptoms are confined to a sparse and indistinct mottling along the veins of some of the leaves. This mottling in some instances is too faint to be detected readily, except in transmitted light, and may be entirely wanting. This behavior of *N. glauca* is rather exceptional and has been the subject of considerable investigation. In February, 1914, a number of young, vigorous plants of that species growing in the greenhouse were inoculated repeatedly with the virus of the mosaic disease until most of them showed more or less evidence of developing disease. Eight of these, which showed more clearly defined symptoms, were finally tested by injecting the expressed sap of each into a series of plants of *N. tabacum*. The sap of all proved exceptionally virulent, producing in most instances 100 per cent of infection in each lot of 10 plants. After the initial expression of the disease the symptoms gradually became more attenuated, until they were barely distinguishable. In July three of these plants were cut back severely and were immediately transplanted to the field. Growth was resumed, but no symptoms of the mosaic disease whatever could be detected. However, inoculation tests have shown that the sap of these plants contained the infective principle of the disease. In October these plants were again taken from the field and transplanted in the greenhouse for the winter. Although growth appeared normal and symptoms of the mosaic disease could not be detected with certainty, experiments have shown repeatedly that the infective principle of the disease was still present in the expressed sap. This behavior of *N. glauca* is not entirely without its analogy, since Baur,[1] working with infectious chlorosis of the Malvaceae, has found by grafting immune with susceptible sorts that the virus of the disease may pass into immune sorts of abutilon without producing any indications of disease. Baur is of the opinion, however, that the virus does not continue to live and to multiply in the infected immune plants after they have been severed from the diseased plants.

Experiments have shown that when scions of the immune species, *N. glutinosa*, have been grafted upon mosaic-diseased plants of *N. tabacum* the infective principle of the disease may pass into *N. glutinosa* without the subsequent development of symptoms of the mosaic disease.

It has not been determined whether the infective principle continues to live and to multiply in such *N. glutinosa* plants after they have been separated from the mosaic diseased plants of *N. tabacum*.

In the case of *N. glauca* it is evident that the infective principle, after being inoculated into the tissues of the leaves, propagates itself readily and becomes disseminated to all parts of the infected plant, producing systemic infection.

Although it has not yet been shown that a permanent systemic infection may occur in young growing plants of *N. tabacum* without the

[1] BAUR, Erwin. ÜBER DIE INFEKTIÖSE CHLOROSE DER MALVACEEN. *In* Sitzber. K. Preuss. Akad. Wiss., 1906, Heft 1, 11–29. 1906.

expression of symptoms, it is known that the infective principle does not necessarily produce evident symptoms wherever it is found. If half-grown plants become infected with the virus of the mosaic disease, the younger leaves show symptoms of disease, while the lowermost mature leaves remain healthy in appearance. Such leaves may contain the infective principle, however, if sufficient time has elapsed for general or systemic infection to take place.

Likewise, if nearly mature plants become infected, the corolla alone may show symptoms of disease. Subsequently all secondary branches become mosaic diseased, showing that the virus has migrated to all parts of the main stem, finally reaching and affecting new growing centers. If such dormant plants are severely cut back, even to the ground, all subsequent sucker growth becomes mosaic diseased.

In large, vigorous plants grown in the field systemic infection sometimes proceeds gradually from branch to branch. This has been shown with large plants producing many suckers. In some instances the uppermost suckers were badly diseased, while others lower down on the stalk appeared normal in all respects.

Although inoculation tests have shown that such suckers in some instances did not contain the active, infective principle at the time the sap was extracted, such suckers invariably become diseased sooner or later.

TRANSMISSION OF THE MOSAIC DISEASE OF TOBACCO BY PLANT LICE

It was first observed in the greenhouses at Arlington, Va., during the winter and spring of 1912 that plant lice were in some manner associated with outbreaks of the mosaic disease of tobacco. Experiments have since shown that the common and well-known green peach aphis, or spinach aphis (*Myzus persicae* Sulz.) may become an active carrier of the infective principle of the disease. These plant lice are very common in the greenhouse and may be found on a great variety of plants. In winter they multiply in great numbers upon tobacco plants and may even produce serious injury to these plants if allowed to multiply unchecked.

Many colonies of these plant lice obtained from different sources have been studied in their relation to the transmission of the mosaic disease. Colonies have been found which have failed to produce infection in healthy tobacco plants. Such colonies have been obtained from belladonna and cabbage plants, which are naturally immune to the disease. Colonies free from infection have also been obtained from healthy tobacco plants. On the other hand, experiments have shown that colonies obtained from mosaic-diseased tobacco plants may become very efficient disseminators of the infective principle of the disease.

In one of the earlier experiments carried out during the winter of 1912, a colony of *Myzus persicae* obtained from belladonna plants was

introduced upon young tobacco plants on January 18. These plant lice multiplied rapidly and remained upon the plants in great numbers throughout January, February, and March. On April 1 the plants were fumigated with the fumes of nicotine obtained by burning paper impregnated with nicotine to destroy the plant lice, which had stunted the plants severely. These plants were allowed to grow for several weeks longer and soon regained their normal green color. At the termination of the experiment none had developed the mosaic disease. A series of control plants of the same age, fumigated at intervals with nicotine fumes obtained as mentioned above to exclude plant lice, remained free from the mosaic disease throughout the period of the experiment.

Other colonies of *Myzus persicae* infesting mosaic-diseased tobacco plants produced the disease in great numbers of young tobacco seedlings kept in screened cages.

During the winter of 1915–16 additional experiments were carried out with colonies of *Myzus persicae* in the greenhouse at Arlington, Va. Colonies of these plant lice which proved to be free from infection were found, and many individuals were then transferred to the leaves of mosaic-diseased tobacco plants and allowed to multiply freely upon them. Individuals which had been reared upon these plants were then transferred with a fine camel's-hair brush to 13 young, healthy Connecticut Broadleaf tobacco plants. Twelve of these plants became mosaic-diseased within five to six weeks, one plant only remaining healthy. At the same time 15 control plants, which were kept free from plant lice at all times, remained free from the mosaic disease throughout the experiment.

In another series of experiments large numbers of *Myzus persicae* were again transferred from mosaic-diseased plants to two flats of very young tobacco seedlings. At the same time two similar flats were inclosed in screened cages and kept free from plant lice. Throughout the entire experiment the plants in these flats remained free from the mosaic disease. At the same time, however, great numbers of mosaic-diseased plants appeared in both flats which had been infested with plant lice transferred from the mosaic plants.

These experiments indicate that the green peach aphid may become an active carrier of the infective principle of the mosaic disease of tobacco; and they also show that these plant lice do not become active carriers of infection until they have been associated with mosaic-diseased plants.

Numerous experiments were also carried out in the greenhouse with a large, green species of plant louse, *Macrosiphum lactucae* Kalt., taken from lettuce plants. Colonies of these plant lice were confined upon mosaic-diseased tobacco plants and finally transferred from these plants at different intervals to very young, healthy tobacco plants. They soon established themselves upon the plants and multiplied so rapidly in

some instances as to produce heavy infestation, but in no instance did they produce infection in healthy plants. As a result of their infestations, however, temporary disturbances of a striking character were produced. Soon after these plant lice had begun to feed upon the young leaves, these became more or less curled and wrinkled, and rather large, conspicuous dark green spots came into evidence as a result of their punctures. This spotting, which only remotely resembled the mottling characteristic of the mosaic disease, was confined entirely to those leaves actually attacked, and disappeared soon after the removal of the plant lice from the plants. This disturbance more properly belongs to the class of disturbances described by Woods [1] as stigmonose, a term which he used to designate a more or less temporary and noninfectious pathological condition produced in carnations by plant lice and other insects.

Colonies of the common pelargonium plant louse (*Macrosiphum pelargonii* Kalt.) were also transferred to mosaic-diseased plants and subsequently to healthy tobacco plants. This plant louse did not take kindly to tobacco, and colonies could not be maintained upon these plants or any length of time—perhaps owing to the fact that they did not feed upon the plants. Transmission of the disease was not obtained with these plant lice; nor were temporary disturbances of any kind produced.

Under field conditions the large plant louse *Macrosiphum tabaci* Perg. appears to be an efficient carrier of the infective principle of the mosaic disease of tobacco. At the Arlington Experimental Farm during certain seasons this plant louse occurs in enormous numbers upon tobacco, tomatoes, datura, and other solanaceous plants. During the spring and summer of 1913 this species appeared suddenly, and swarmed upon these plants. Minor outbreaks have also occurred in subsequent years. There is strong reason for believing that the widespread epidemic of mosaic disease which affected tobacco, tomatoes, and datura during the season of 1913 at Arlington, Va., was associated with the presence of these plant lice. In late May and early June, soon after the young tobacco plants were transplanted to the field, colonies were found upon the undersides of the ground leaves of practically every tobacco plant in the field. These plant lice multiplied rapidly and remained upon the plants until early July. After this period they disappeared so completely from the plants that it was almost impossible to find a single individual in late July and August. In late September, however, heavy infestations were observed on tomato plants.

This plant louse rarely occurs in the greenhouses at Arlington. Recently seedling tobacco plants have been grown in screened cages out of doors and colonies of this plant louse taken from mosaic-diseased tobacco plants have been confined upon them for varying periods. Under these conditions successful transmission of the disease was obtained.

[1] WOODS, A. F. STIGMONOSE: A DISEASE OF CARNATIONS AND OTHER PINKS. U. S. Dept. Agr. Div. Veg. Physiol. and Path. Bul. 19, 30 p., 5 fig., 3 pl. 1900.

In several instances the plant louse *Macrosiphum tabaci* has become established in the seed beds at Arlington, and appears to have been associated with outbreaks of the mosaic disease which appeared in the infested areas.

Under greenhouse conditions experiments indicate that plant lice may become important disseminators of infection. Experience has also shown that the occurrence and spread of the disease in the greenhouse can not be controlled so long as the plant louse *Myzus persicae* is allowed to multiply unchecked.

If plant lice are excluded by fumigation, however, the occurrence and spread of the mosaic disease of tobacco becomes a negligible factor, provided contamination of the plants in the process of handling does not take place. Although white flies (*Aleyrodes vaporariorum* Westw.) are also troublesome pests upon tobacco in the greenhouse, they do not appear to be actively concerned with the spread of the disease. Preliminary experiments with these insects, obtained from mosaic-diseased plants and confined upon healthy plants in screened cages, have also given negative results. Red spiders (*Tetranychus telarius* L.), which do not take kindly to tobacco, have given the same results.

Although in the United States plant lice do not appear to be especially troublesome pests on tobacco in the field, it appears that they sometimes cause serious injury to tobacco in Europe and elsewhere. Preissecker [1] states that during some seasons they fairly cover the leaves of tobacco plants and produce far more injury than is usually estimated. It is especially interesting to note that Preissecker [1] has also observed that the mosaic disease of tobacco is associated with attacks of plant lice..

Die von Blattläusen verwundeten Blätter sind begreiflicherweise später gewöhnlich auch von anderen Krankheiten (Pilzen, Mosaik- und Pockenkrankheit) viel mehr heimgesucht als die unbeschädigten, und es ist deshalb von allem Anfange auf die Entfernung und Fernhaltung der Blattläuse ein besonderes Augenmerk zu richten.

Preissecker again discusses the widespread occurrence of plant lice upon tobacco in the Imoskaner region in a later article,[2] and mentions that the species *Myzus plantaginis* Pass. is very common on tobacco in Dalmatia. Other species are also mentioned. He states that plant lice are especially injurious to young plants in the seed bed. Concerning the abundance of plant lice upon tobacco in the field, he[2] says:

Im Jahre 1903 gab es von Anfang Juni bis zur Ernte Blattläuse auf Tabak im ganzen Imoskaner Bezirke; man traf Pflanzungen in denen jeder Stock on allen Mutter- und- Spitzblättern, u. zw. meist auf beiden Seiten derselben, von den Läusen so dicht besetzt war, dass sie hier und da übereinander kriechen mussten, um Platz zu finden. . . .

[1] PREISSECKER, Karl. EIN KLEINER BEITRAG ZUR KENNTNIS DES TABAKBAUES IM IMOSKANER TABAKBAUGEBIETE. *In* Fach. Mitt. Öesterr. Tabakregie, Jahrg. 3, Heft 2, p. 1–31, 19 fig. 1903.

[2] PREISSECKER, Karl. EIN KLEINER BEITRAG ZUR KENNTNIS DES TABAKBAUES IM IMOSKANER TABAKBAUGEBIETE. *In* Fach. Mitt. Öesterr. Tabakregie, Jahrg. 5, Heft 1, p. 1–44, fig. 41–75 (1 pl.). 1905.

Although Preissecker casually observed that there was some relation between the presence of plant lice upon tobacco plants and the subsequent occurrence of the mosaic disease, it does not appear that he looked upon them as actual carriers of the infective principle of the disease.

SUMMARY

(1) The virus of the mosaic disease of tobacco is present in the trichomes of the leaves, as well as in the tissues of the lamina. The disease may be communicated to healthy plants by inoculating the virus into the trichomes alone.

(2) The infective principle of the disease does not readily invade uninjured trichomes or leaf tissues when merely sprayed upon the plants. Infection readily follows when the virus is sprayed upon the leaves and subsequently rubbed in.

(3) Infection is more likely to follow if the virus is inoculated into the leaves at more than one point.

(4) Cutting across the midrib at the base of the leaf, or severing all the larger veins on one or both sides of the midrib, does not prevent the final dissemination of the virus from distant points of inoculation in the leaf to other leaves on the plant.

(5) Thorough washing with soap and water serves to remove the virus from the hands for all practical purposes.

(6) Thorough steam sterilization of the soil of the seed bed completely destroys any virus of the mosaic disease of tobacco which may be present in the soil.

(7) The mosaic disease of tobacco does not necessarily follow when large quantities of mosaic-diseased material are introduced into the soil so that the roots of healthy tobacco plants must ultimately reach it. Infection from such material appears to depend upon injury to some portion of the root system which allows the virus to enter at these points. It is possible that root parasites may sometimes produce this injury to the roots and root hairs.

(8) The species *Nicotiana glauca* is susceptible to the mosaic disease of tobacco, although visible symptoms of the disease may be very slight. The sap of such plants, although apparently but little affected by the disease, so far as visible symptoms are concerned, is highly infectious to healthy plants of *N. tabacum*.

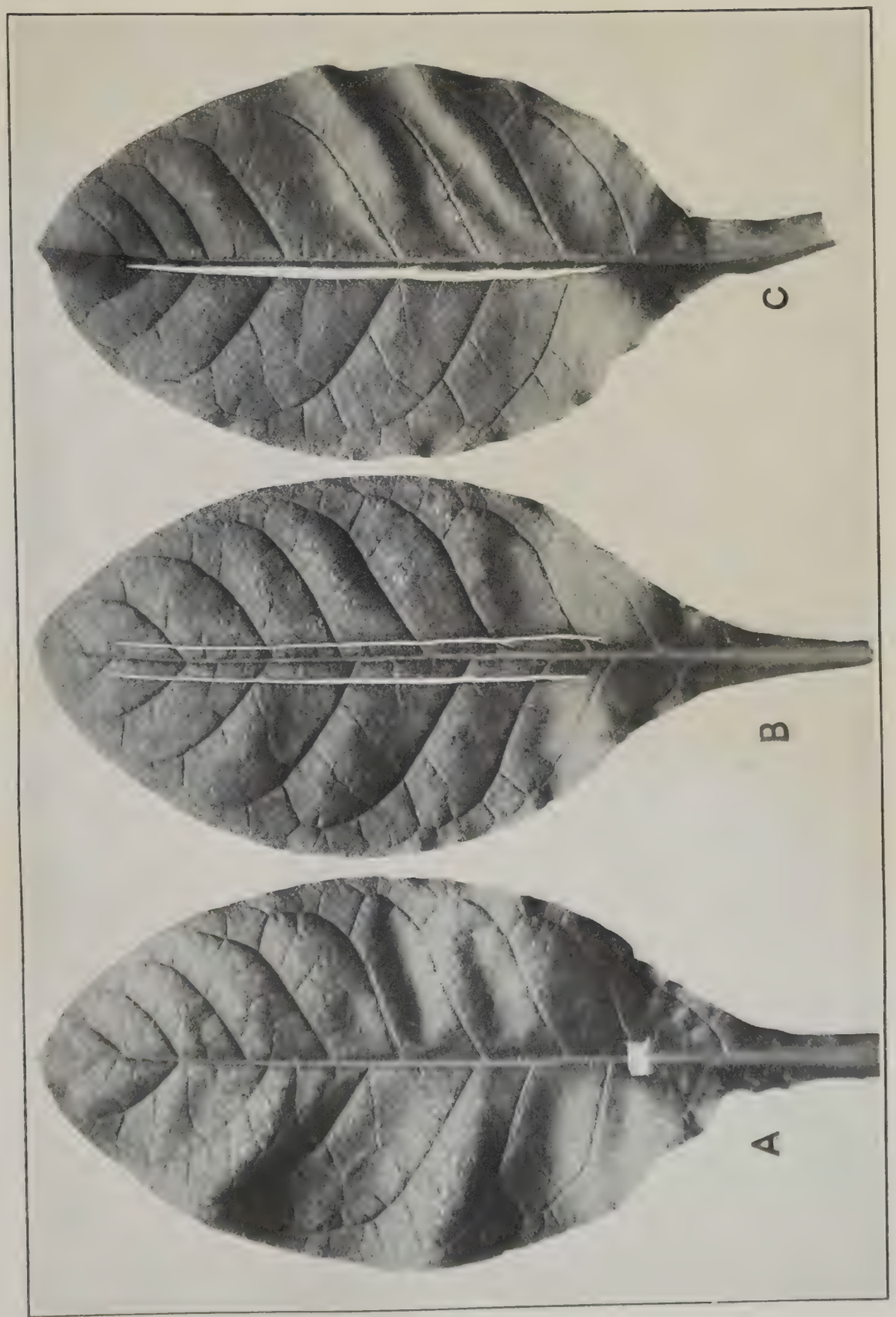
(9) Some species of aphids may become active carriers of the infective principle of the mosaic disease. Experiments have shown that the green peach aphis (*Myzus persicae*) may become an active carrier of infection in the greenhouse, after it has been feeding upon mosaic-diseased plants. Not all species of aphids appear to transfer the disease with the same readiness. Negative results were always obtained with the large lettuce aphis, *Macrosiphum lactucae*. Under field conditions the large plant louse *Macrosiphum tabaci* which sometimes becomes very common on

solanaceous plants, appears to be an efficient carrier of the infective principle of the disease.

(10) Red spiders, which rarely attack tobacco in the greenhouse have consistently given negative results so far as the transmission of the disease is concerned. White flies, which are often very troublesome pests upon tobacco in the greenhouse, do not appear to be actively concerned with the transmission of the disease.

PLATE 63

Leaves of tobacco showing method of severing the midrib and lateral veins in studying the distribution of the virus from the point of inoculation. Leaf A, midrib severed at base. Leaf B, lateral veins on both sides of midrib severed. Leaf C, lateral veins on one side of midrib severed.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A STUDY OF THE PROTEINS OF CERTAIN INSECTS WITH REFERENCE TO THEIR VALUE AS FOOD FOR POULTRY

By J. S. McHargue,[1]

Assistant Chemist, Laboratory of Chemical Research, Kentucky Agricultural Experiment Station

In view of the present high cost of living, it is well to discuss and to consider seriously the utilization of every available source of sound animal protein, even though such proteins may have hitherto been looked upon as of not enough economical importance to warrant their utilization.

The object of this paper is to call attention to the efficiency of animal proteins as compared to vegetable proteins, and also to show by comparative analyses that two very common insects contain proteins which are very similar in character to those contained in the proteins of the higher animals which furnish a large part of our food supply.

Within recent years wonderful progress has been made in our knowledge of the character and properties of proteins. Formerly it was assumed that all proteins were of equal value in maintaining nitrogen equilibrium, regardless of whether such proteins were of animal or vegetable origin.

Thomas (2),[2] who was a pupil of Rubner, was the first to demonstrate experimentally the fact that animal proteins are much superior to vegetable proteins in maintaining nitrogen equilibrium in the animal body.

In order to demonstrate this fact, he performed the following classical experiment on his own body. In his diet he took large quantities of starch and sugar, and determined the minimum loss of protein under these conditions. He then took meat protein in an amount equivalent to this minimum quantity destroyed and found that if the food was divided into six portions, taken four hours apart, there was no loss of body protein. His experiments were carried still farther, and he showed the relative biological values of proteins of different origin. The following list shows the minimum amounts of different proteins required to protect body protein from loss:

	Gm.		Gm.
Meat protein	30	Bean protein	54
Milk protein	31	Bread protein	76
Rice protein	34	Indian corn protein	102
Potato protein	38		

[1] The writer begs to acknowledge his indebtedness to the late Dr. J. H. Kastle, who was much interested in nutrition problems and had suggested a study of the proteins of the grasshopper.

[2] Reference is made by number to "Literature cited," p. 637.

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He also states that there can be no doubt whatever as regards the superior value of the proteins of meat, fish, eggs, and milk over those of bread, beans, and Indian corn. The proteins of rice and potatoes hold an intermediate position.

The difference in the efficiency of animal versus vegetable proteins is further demonstrated by most wild animals in their natural selection of food. It is well known that all wild animals of the cat species live altogether on animal proteins. A recent investigation by the United States Biological Survey (1) in regard to the character of the food consumed by the wild birds of this country reveals the very interesting fact that an average analysis of the contents of the craws of 14 species of wild birds shows that approximately 50 per cent of all the food consumed in a year's time consisted of animal matter in the form of insects. If the fact that insects are only available for about six months of the year is taken into consideration, it is to be assumed that the diet of the wild birds consists almost entirely of animal protein during the season in which insects are available. It is also to be noted in this connection that the parent birds feed their young on a purely animal diet, thus exhibiting a wonderful instinct in the selection of a food that is most efficient for the rapid growth of their young. The avidity with which domestic fowls, when allowed to range, seek insect food is familiar to all, and it is a well-known fact that poultry thrive best when they have access to this kind of food.

After noting these phenomena in the selection of food by both wild and domesticated birds, it is only natural to inquire whether there is any chemical evidence as to the nature of the proteins contained in the various insects which will substantiate the birds' instinctive selection of this particular kind of food.

Through the recent researches of Osborne and Mendel (3–5) of Yale University and the Connecticut Experiment Station, it has been conclusively shown that the growth-promoting properties of certain proteins are due to the presence of that kind of protein which is capable of yielding upon hydrolysis the amino acids lysin, cystin, and tryptophane. Then, if the instinct of the bird in its selection of its food is a true guide, we would expect a protein analysis to show a considerable amount of these growth-promoting amino-acid groups present in this type of food.

In fact, protein determinations made by the writer on two common insects, the June bug (*Lachnosterna* sp.) and the grasshopper (*Melanoplus* spp.), showed such a large percentage of protein present in the dry state that a further study of the character of the proteins present, as revealed by the Van Slyke method for protein hydrolysis, was carried out. The results obtained are shown in Table I, under the proper headings, together with the results obtained by the same method of analysis on a very tender piece of cooked beef roast and the cooked tender white breast meat of a turkey. The specimens of beef roast and turkey were

selected for comparison because they represent the more common higher types of animal proteins.

TABLE I.—*Percentage of amino-acid groups in animal proteins from different sources*

Group.	Grasshoppers.	June bugs.	Beef roast.	Turkey white meat.
Ammonia nitrogen	9. 14	8. 96	3. 27	5. 65
Melanin nitrogen	3. 42	6. 78	5. 22	1. 72
Arginin nitrogen	14. 98	11. 53	15. 44	14. 72
Histidin nitrogen	5. 62	6. 57	13. 34	18. 23
Cystin nitrogen	. 23	. 35	. 49	. 47
Lysin nitrogen	8. 04	8. 02	8. 40	7. 67
Amino nitrogen (in filtrate from bases)	52. 87	50. 80	40. 89	42. 41
Non-amino nitrogen (in filtrate from bases)	4. 32	5. 84	9. 38	7. 26
Total	98. 62	98. 85	96. 43	98. 13

As a whole, the results show considerable similarity for proteins varying so widely in their sources of origin. The chief points to be taken into consideration in an analysis of this kind, as showing important points in similarity or differences, are the four amino-acid groups, arginin, histidin, cystin, and lysin. In the arginin determinations very closely agreeing results have been obtained on each of the different proteins analyzed. In the histidin determinations there is considerable variation. The result for this group in the first and second analyses is one-half of that in the third and one-third of that obtained in the fourth analysis. Figures for the cystin group show an increase of one-half in the second analysis over the first, and more than twice as much in the third and fourth analyses as in the first. The determinations in the lysin group show a remarkably close agreement in all the analyses. In the light of our present knowledge this is by far one of the most important groups contained in proteins, from the standpoint of growth and nutrition.

For the purpose of showing further points of interest in connection with the grasshopper the following work was carried out:

On September 23, 1916, about 200 gm. of grasshoppers were caught, killed by means of potassium cyanid, dried at 100° C. until free from water, ground in a mortar, and placed in a ground-glass-stoppered bottle. With the exception of the opening of the bottle for weighing out portions for protein, fat, and mineral-constituent determinations, the material has remained in the laboratory unmolested until the present time. A protein determination made recently on the same material after standing in the laboratory in this condition for seven months shows that there has been no alteration in the protein content during this period of time, which demonstrates that the dry material can be kept indefinitely.

The following determinations were made on the moisture-free material:

	Per cent.
Protein	75.28
Fat (ether extract)	7.21
Ash (crude)	5.61
Mineral constituents:	
Silica	.600
Iron oxid (Fe_2O_3)	.107
Manganese oxid (Mn_3O_4)	.008
Calcium oxid	.360
Magnesium oxid	.394
Potassium oxid	1.202
Sodium oxid	.335
Phosphorus pentoxid	1.190
Sulphur	.380
Carbon dioxid and unconsumed carbon, by difference	1.034
Total mineral constituents	5.610

From the results obtained in the analysis of the water-free substance it is to be observed that the dried remains of grasshoppers contain a high percentage of valuable protein and also notable amounts of fat, phosphorus, and potassium.

At different periods in the world's history this insect has occurred in such great numbers as to make it necessary to provide means for its immediate destruction. Whiting (8) describes a plague of locusts or grasshoppers which occurred in Palestine in the summer of 1915. He characterizes this plague as being one of the greatest of all grasshopper plagues on record, both in regard to numbers and to the amount of destruction done. The following paragraph is taken from his article (8, p. 513):

> Quantities were now gathered by the poorer Bethlehemites. A few ate them roasted, describing the taste as delicious, especially the females full of eggs. Still the main reason for collecting them was in order to secure the small bonus offered by the local government of Bethlehem. Thus tons were destroyed, being buried alive till several ancient abandoned cisterns were filled, while in surrounding villages each family was required to produce a stipulated weight. Likewise in Jaffa they were destroyed by being thrown into the Mediterranean, and when washed ashore dead and dried on the beach, were collected and used as fuel in the public "Turkish baths" and ovens.

While there has never been such a plague in this country as the one just described, grasshoppers have been known to occur in such numbers as to make it necessary to provide means for their control (6). Walton (7) in a bulletin of the United States Department of Agriculture, cites instances where as many as 3 bushels of grasshoppers have been harvested per acre by means of a mechanical device known as the grasshopperdozer. It is quite probable that in many instances with suitable machinery for catching, drying, and grinding these insects they might afford a new source of a high-grade protein in all respects the equivalent of meat meal, which could be made to serve an economical use in the affairs of man, such as preparing balanced rations for swine, poultry, and other live stock.

June bugs, while containing a slightly greater amount of protein than the grasshopper, and of equal value, could not be made an economical source of protein because of their limited number and the short time in which they are available.

From the data herein contained we may draw the following conclusions:

(1) That the instinct in wild and domesticated birds which guides them in their natural selection of the most efficient food is confirmed by the high lysin content found in the insects thus far examined.

(2) That grasshoppers deprived of their moisture contain a higher protein content than commercial meat meal, and in all probability could be made an efficient substitute therefor.

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WIND-BLOWN RAIN, A FACTOR IN DISEASE DISSEMINATION

By R. C. FAULWETTER,

Associate Botanist and Plant Pathologist, South Carolina Agricultural Experiment Station

INTRODUCTION

In an earlier article [1] the author presented data from field experiments which lead to the conclusion that the spread of that disease was due to the combined action of wind and rain. It was also shown that the spread of similar diseases of plants affecting the leaves, flowers, fruits, and twigs, caused by motile bacteria had not been satisfactorily explained by investigators, while nothing in the literature on the subject precluded the possibility of such an explanation applying equally as well in these cases. Numerous statements appear which permit a very general application of this explanation.

The film of water over the surface of the affected leaves caused by dew contains viable bacteria which emanate from the lesions, as was demonstrated by several experiments, and it was held to be reasonable that this condition would exist during rains. The spread of such a suspension of bacteria by the combined action of wind and rain most plausibly explained the dissemination of the disease noted in the field.

Experiments have been conducted with the object of analyzing this agency of disease dissemination, and, so far as the results of laboratory tests permit application to natural and field conditions, added support to the earlier conclusions has been the result. The method and the results of these experiments in which the influence of size of drops, distance of fall, depth of surface film, elevation and inclination of surface film, and motion of the air upon the distance of splash have been studied are presented here, together with a consideration of the importance of this agency of disease dissemination, which is justified by the newer information.

METHOD AND APPARATUS

Several drawn-glass droppers of different diameter were made and fitted separately to a burette having a glass stopcock. The diameters were such as permitted drops of 0.02, 0.04, 0.06, and 0.1 c. c. in volume to fall. Such surfaces as dry glass plates, dry blotting papers, wet glass plates, saturated blotting papers, and water 1 cm. deep in a petri dish were used and in this way the results of the fall upon a dry impervious surface, a dry porous surface, a very thin film of water (such as would

[1] FAULWETTER, R. C. DISSEMINATION OF THE ANGULAR LEAFSPOT OF COTTON. *In* Jour. Agr. Research, v. 8, no. 12, 457–475, 2 fig. 1917. Literature cited, p. 473–475.

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remain over a saturated piece of blotting paper), a medium layer of water (such as would remain upon a clean, level glass plate) and a very thick layer of water (as that in a petri dish) were observed.

In the earlier work a large pane of glass ruled with a series of concentric arcs varying successively, 2 inches in radius, similar though on a much larger scale to the Jeffers counting plate used in bacteriological laboratories, was used to determine the number and position of the splash drops. Later two such panes of glass placed end to end were used and these afforded a total distance of 114 inches, which served all needs until the wind factor was introduced. At the latter stage of the work acetic acid was applied to the point of impact by a finely drawn siphon and with neutral or slightly alkaline litmus blotters 6 inches square placed in the path of the wind the limits of splash were easily determined.

The level surface used at the plane of the counter was supported upon two strips of glass placed across a small tray. When inclined surfaces were used, or the level surface elevated above the counter, a glass plate was placed in a clamp and fastened to a ring stand. The level plates were adjusted with a spirit level and the inclined ones were placed at definite angles to the level plate, as is noted below. The blotting paper surfaces were always placed upon a glass plate whether used dry or wet, level or inclined.

NATURE OF A SPLASH

A single drop falling 12 inches onto a clean dry glass plate does not cause a splash. This was repeated 100 times with each size of drop with the same result. The same is true of a drop falling 24 inches, while at 48 inches the largest drop (0.1 c. c.) did break in a few instances and scatter splash drops over the counter. When, however, two drops fall consecutively upon the same spot, even the smallest (0.02 c. c.) will cause a splash when falling but 12 inches.

This experiment, repeated with pieces of dry blotting paper, gave the same result in the case of single drops, though with the largest drop falling 12 inches an increasing number of splash drops appeared after 2, 5, and 10 drops were allowed to fall upon the same place, showing that the nearer saturated the blotting paper became, the more water became available in the surface film, and this was broken up and scattered by the impact of the falling drops.

A dilute eosin solution was applied to the surface of the glass plate and the saturated blotting paper in many of the experiments, and in all such cases the stain appeared upon the counter. When acetic acid was supplied to the plate at the point of impact as mentioned above, one never failed to note the change of color of the litmus paper where splash drops fell upon it.

These facts justify the conclusion that the splash drops scattered from the point of impact of a falling drop are made primarily of the water

composing the surface film at the point of impact. Perhaps in some cases water of the fallen drop is scattered, but the greater part of it remains as a part of the surface film and is splashed by succeeding drops.

NUMBER AND DISTRIBUTION OF SPLASH DROPS

While it was a relatively simple process to find the distances of those splash drops scattered farthest over a quadrant of a circle on the counter which was used, it was difficult to obtain an accurate count of the total number of splash drops in this way. In every instance many of the smaller drops, varying from a sixteenth of an inch in diameter to zero, evaporated before the count could be completed. Finally, to determine this point, the acetic-acid and litmus-paper method was resorted to. Five 0.02-c. c. drops falling 16 feet upon a glass plate covered with a solution of acetic acid scattered 495 drops over an eighth of a circle between 2 and 24 inches from the point of impact. When calculated, these figures show that each drop of that size falling that distance broke off and scattered 795 drops over a circle with a 24-inch radius.

The distribution of these splash drops is given in Table I, and it will be noticed that the modal class or distance is between 4 and 6 inches; yet the mean distance when determined is 7.1 inches.

TABLE I.—*Number of splash drops in concentric circles of varying radii, with the determination of the mean distance of all the drops*

Drops between circles of given radii.		Calculation of the mean distance.	
Radii.	Number of drops.	Distance of the class.	Product.
Inches.		*Inches.*	
0 to 2	32	1	32
2 to 4	824	3	2,472
4 to 6	1,008	5	5,040
6 to 8	800	7	5,600
8 to 10	472	9	4,248
10 to 12	384	11	4,224
12 to 14	288	13	3,744
14 to 16	96	15	1,440
16 to 18	16	17	272
18 to 20	32	19	608
20 to 22	8	21	168
22 to 24	16	23	368
	3,976	.....	28,216÷3,976=7.1 inches, mean.

A reproduction of the distribution of these drops is given in figure 1, showing the relative distances and orientation more satisfactorily than that of the foregoing table. A fact prominent in this phase of the work is the presence of the larger splash drops at the extreme distances. The smaller ones are more abundant near the point of impact. With-

FIG. 1.—Graph showing the number and distribution of splash drops from five 0.02-c. c. drops falling 16 feet upon wet glass plate over an eighth of a circle.

out doubt all are cleaved from the surface film at the same time, and all leave the point of impact with the same energy. The only explanation for the presence of the larger drops at the greater distances must lie in the difference in resistance offered by the atmosphere, since the smaller drops would experience greater relative resistance than the larger ones.

SPLASH FROM A HORIZONTAL SURFACE AT THE LEVEL OF THE COUNTER

The greatest distance of splash results from the fall of the largest drop onto the thin film of water afforded by the wet blotting paper when falling 12 inches. Other things being equal, the distance of splash varies as the size of the drop varies, though not in direct proportion. With drops of each size, respectively, the distance of splash is greater from the wet glass plate than from the water in the petri dish.

The same relation exists in all the tests made with the drops falling 24 and 48 inches, with the exception in the latter case, where the distances from blotting paper and the glass plate were equal in two instances. With the tests made at greater heights, 8 and 16 feet, the thick layer of water in the petri dish was eliminated, since such a factor has no place in the application of the work to field conditions and since the relation of a deep layer of water to the other layers used had been satisfactorily established.

The figures given in Table II represent the extremes of splash in inches under each of the various sets of conditions and in general show the relation between size of drops, distance of fall, and thickness of surface film in the determination of this distance. The mean distance of all the splash drops farther than 6 inches resulting from the 1-, 2-, and 4-foot falls and the average of the extremes of each of 50 single drops falling 8 and 16 feet present the same relation of factors.

TABLE II.—*Distance (in inches) of splashes, giving the maximum, mean, and average of the maximums in 50 trials*

Size of drop.	Surface of impact.	Maximum.					Mean.			Average of maximums.	
Distance of fall .... feet		1	2	4	8	16	1	2	4	8	16
C. c.											
0.1	Blotting paper	26	34	40	54	56	13.5	18.1	20.8	40	45
	Glass plate	20	36	40	42	48	12.0	15.5	17.8	33	35
	Petri dish	18	22	28	.....	.....	9.3	13.1	14.1	.....	.....
.06	Blotting paper	24	30	38	42	46	12.2	15.3	18.4	39	36
	Glass plate	20	14	36	32	40	10.9	12.8	17 0	28	29
	Petri dish	14	18	22	.....	.....	8.4	11.4	13.4	.....	.....
.04	Blotting paper	18	22	32	36	40	10.8.	13.2	15.9	29	33
	Glass plate	12	16	32	24	38	8.7	9.5	14.8	19	26
	Petri dish	12	16	20	.....	.....	8.1	9.3	11.1	.....	.....
.02	Blotting paper	16	26	32	30	34	8.6	12.8	14.9	26	26
	Glass plate	10	16	26	24	24	7.3	9.9	11.6	15	18
	Petri dish	0	14	16	.....	.....	0.0	8.8	9.5	.....	.....

SPLASH FROM AN ELEVATED HORIZONTAL SURFACE

The total impetus of the splash drop is not expended in the experiments described above as is shown by the results obtained when the surface of impact is elevated above the counter. These observations were made with drops falling 16 feet upon a glass plate and a wet blotting paper surface elevated 24 inches above the counter, and the results are tabulated in Table III. In the case of the 0.02-c. c. drop falling onto the glass plate data are given for elevations of 3, 4, and 7 feet.

TABLE III.—*Distance (in inches) of splashes from horizontal surfaces, drops falling 16 feet*

Size of drop.	Surface of impact.	Maximum distance after many (100+) drops had fallen.				
Elevation of surface above counter ..... inches ..		0	24	36	48	84
C. c.						
0.1	Blotting paper	56	64	.....	.....	.....
	Glass plate	48	72	.....	.....	.....
.06	Blotting paper	46	56	.....	.....	.....
	Glass plate	40	64	.....	.....	.....
.04	Blotting paper	40	54	.....	.....	.....
	Glass plate	38	56	.....	.....	.....
.02	Blotting paper	34	36	.....	.....	.....
	Glass plate	34	40	42	38	42

SPLASH FROM AN INCLINED SURFACE

The orientation of the splash drops from a glass plate inclined 45° at the level of the counter differed from those from the level plate. With the semicircles of the counter divided into one central quadrant and two bordering octants and the centers coinciding with the point of impact, the splash drops arranged themselves in greatest numbers over the octants at the sides. Fewer drops fell just within the limits of the quadrant, while more fell along the median line. The latter never attained the distance of those at the sides. When leaving the point of impact, they ascend very little, if at all, but travel outward and downward. Those going to the sides ascend at first and then fall, similarly to the splash drops from a level surface.

As in this case, too, the total impetus is not expended when the surface is at the level of the counter. With the elevation of the inclined surface the net result of the glancing blow of the falling drop is observed. Those splash drops traveling along the median line of the counter—that is, at right angles to the inclined surface—increase in extreme distance until the optimum elevation is reached, where they exceed the distance of those going to the sides. The results of the 0.02-c. c. drop falling 16 feet upon the glass plate level and inclined 30° and 45° at various elevations above the counter are given in Table IV. It is to be noted that the maximum distance of splash is least from the level plate and greatest from that inclined 30°.

TABLE IV.—*Maximum distance (in inches) of the splash of a 0.02-c. c. drop falling 16 feet upon level and inclined wet glass plates*

Elevation of surface of impact above counter.	Level plate.	Plate inclined 45°.	Plate inclined 30°.
Feet.			
0	24	28	46
1	.....	.....	50
2	40	52	56
3	42	52	60
4	38	52	66
5	.....	.....	64
7	42	.....	66

EFFECT OF WIND UPON DISTANCE OF SPLASH

As mentioned above, the methods of the experiments were altered when wind was introduced into the work. An 18-inch electric fan was standardized with a wind gauge. While running at its greatest speed, the air was moving at the approximate rate of 10 miles per hour, 5 feet from the fan. In the experiments conducted, the fan was placed 5 feet from the surface of the splash, which itself was elevated 3 feet above the floor. Drops were permitted to fall 16 feet onto a clean glass plate which was very slightly inclined, in order that the surface film might be relatively thin. Dilute acetic acid was supplied to the plate near the point of impact by a siphon from a reservoir. In this way the falling drop scattered a solution of acetic acid and the wind blew these splash drops at the approximate rate of 10 miles per hour. The velocity of the wind was being constantly retarded by friction with the surrounding quiet air, and in this respect the extreme distance of splash was less than it would have been had the whole air mass been moving at the same rate. Litmus blotters were placed upon the floor at distances of 6, 8, 10, 12, 14, 16, and 18 feet from the point of impact in the path of the wind. After an hour's running the blotters at 6 and 8 feet were almost entirely red, those at 10, 12, and 14 feet were well spotted with red, while that at 16 feet showed several, and at 18 feet two red spots. Thus, it is evident that water was blown as far as 18 feet under the conditions of this experiment.

It was noted above that the larger splash drops exceeded the distance of the smaller splash drops. This does not obtain when the splash takes place in the wind, since the direction of atmospheric resistance is altered, and the smaller drops are borne farther than the larger, heavier ones. Considering the fact that splash drops vary in size from 1/8 inch in diameter to zero, the smallest ones may be carried correspondingly greater distances than the larger. These, without doubt, evaporated in transit in our experiments because of the dry atmosphere in the laboratory. In a humid atmosphere it is possible these may be carried

farther. Continual collisions between splash drops and rain drops occur in the field, and because of this many of the former may never reach their extreme distance at the prevailing wind velocity, though, without doubt, some of them will exceed the distance determined in the laboratory.

COMPARISON OF THESE METHODS WITH NATURAL CONDITIONS

It may be true that there are points in the discussion of these experiments where the justification for comparison is less than in others, yet on the whole, the results indicate the probabilities which exist, and these probabilities confirm the conclusions reached in the field where the spread of the angular leafspot of cotton was observed. An analysis of all the factors in their resemblance to natural conditions is made, in order to remove whatever doubt may exist on this point.

The drops of the sizes used afford a means of comparison of the effect of size and volume of drop on the number of splash drops and the distance of splash. It is recognized that the larger drops used are much larger than raindrops, yet the smallest one comes well within the limits of those in a winter rain where comparisons were made. It was found that drops of the same volume falling equal distances upon dry blotting paper cause wet spots of relatively equal sizes—that is, 25 of the 0.02-c. c. drops falling 16 feet made spots on the blotting paper with a minimum diameter of 14 mm., a maximum of 18 mm., and an average of 16.03 mm. The 0.04-c. c. drop made a spot with a minimum diameter of 19 mm., a maximum of 25 mm., and an average of 21.08 mm. Of 106 drops measured during a rain on the morning of February 20, 1917, fourteen drops were within the limits of the 0.02-c. c. drop as measured and compared in the way outlined above. Those of a summer rain have a greater average volume so that they more closely equal the size of the 0.02-c. c. drop used. It is only this drop which is compared to raindrops, though the others used show the variation in the results due to the variation of this factor.

None of the surfaces used can be closely compared with those of cotton leaves, though that condition is approximated most closely by the inclined glass plate. In that case the glass surface holds a film of water thicker than the blotting paper does and thinner than that of a level plate. There are places about the margins and veins of leaves where water gathers to greater depths than over the other parts, so that a variation of depth of film exists which is approximated by some one or another film used.

The stability of the surface of impact in the experiments is a factor which does not exist in the field. Leaves during a storm are constantly in motion and the petiole affords a springlike support which permits the leaf to yield after the impact of a drop. There are numerous instances also in which the leaves meet the falling drop while moving

toward it in the wind and increase the force of impact, in that way increasing the number of splash drops and distance of splash.

The greatest distance of fall (16 feet) was the highest available in the laboratory. The smallest drop used had probably reached its maximum velocity when falling this distance. If the distance of splash as a measure of the force of impact is an indication of the velocity of the falling drop, this is true, as is shown in Table II, where the distance of splash at 4, 8, and 16 feet from blotting paper and glass plates are relatively the same. This conclusion supports our measurement of raindrops as compared to the 0.02-c. c. drop, since the atmospheric resistance retards an acceleration of velocity beyond a definite maximum, and both our 0.02-c. c. drop and the raindrops had reached this maximum when they were measured.

The influence of the wind was not further investigated because of the limited apparatus available. The fan used produced a velocity of 10 miles per hour at a distance of 5 feet. It was thought best to keep that far from the fan because of the small size of the air cone in motion nearer it. At the distance used, all the air surrounding the surface of impact was moving uniformly and the conditions were most favorable. When it is noted that the distance of splash was increased by such a wind velocity to 18 feet and that this velocity is almost a constant feature of the summer thunderstorms of this region, it is readily seen that this distance of splash is not to be unexpected in the field. In the graphs in the article already cited [1] it is shown that—

> the wind reaches a velocity of 25, 29, and 35 miles per hour during periods in the storms when rain is falling heavily and after the foliage has been wet for some time.

While it has not been determined, it is most probable, all things being considered, that the distance of splash will vary directly with the wind velocity. If water is splashed 18 feet by a wind blowing 10 miles per hour, it will splash approximately 50 feet at 30 miles per hour.

The elevation of the surface of impact in the experiment in which the effect of the wind was observed was 3 feet, and this is entirely within the range of the height of cotton leaves, many being higher than this during the latter half of the season. It is shown in Table III that the splash drops from the 0.02-c. c. drop falling 16 feet reach their maximum distance at this elevation in a still atmosphere.

CONCLUSIONS

It has been shown by experiment that water is splashed by a falling drop only when it falls upon a film of water, and it is the water of the film which composes the splash drops. The distance of the splash varies according to the size of drop, depth of surface films, elevation and inclination of surface of impact, and the velocity of the wind. Field conditions have been duplicated with sufficient accuracy to justify the con-

[1] FAULWETTER, R. C. Op. cit., p. 465.

clusion that these facts hold true in the field during any rainfall; and, in view of my previous experiments showing the emanation of motile bacteria from lesions into the surface water film, their dissemination is the natural result.

It was stated in the paper cited above[1] that—

> unless a great amount of this spread took place at one time, it would have been difficult to understand how the disease could progress so far in one direction if each spot took 8 to 10 days to appear.

And the second inoculation experiment in which bacteria were used which had never been in culture failed to clear the question. The data presented here, however, show that it was entirely possible for most of the spread to have taken place at one time, though no records of wind velocity during the two thunderstorms of June, 1916, are available.

In the experiment in which the effect of the wind was studied all the factors were within the limits of field conditions. A drop of 0.02 c. c. in volume falling 16 feet upon a relatively thin film of water which was splashed, as is proved by the acetic-acid distribution, upon a plate 3 feet above the floor during a wind of 10 miles an hour, splashed water in abundance a distance of 8 feet (across two rows of cotton) in moderate quantities as far as 12 feet (three rows) and in slight amounts to 16 feet. To quote again from the former paper:[2]

> The possibilities of this chain of action during a driving rain are considerable if one includes the distance bacteria may be carried from the original lesion, then splashed up again and carried farther, and so on, until a dilution too great for infection is obtained.

Local dissemination of such diseases as described by Rolfs, Pierce, and others is well within the limits of probability in the presence of dew and heavy fogs without wind. Each drop (the drops from leaves are larger than the average raindrops) falling 12 inches upon a film of water will scatter splash drops over an area of 20 to 32 inches in diameter. The rapidity with which local dissemination of such diseases takes place is easily accounted for.

One could well expand this discussion to include the applications of these conclusions to other similar diseases, but, since no opportunity has been had to study the conditions under which such dissemination must take place, this phase is omitted for the present. However, one can readily understand the possibilities if he takes into consideration the increase of extreme distance of splash due to greater elevation of surface of impact as would occur in pear, walnut, and Citrus trees and greater wind velocity, as occurs in typical thunderstorms of this region and especially during the hurricanes frequent in the southeastern Citrus regions.

[1] FAULWETTER, R. C. Op. cit., p. 467. [2] Idem, p. 470.

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